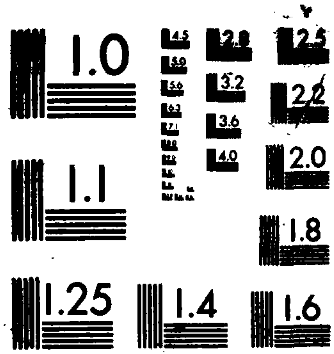
AD-A185 242 ONR FAR EAST SCIENTIFIC BULLETIN VOLUME 12 NUMBER 2 APRIL-JUNE 1987(U) OFFICE OF NAVAL RESEARCH LIAISON OFFICE FAR EAST APO SAN FRANCISCO 96503 1/2

UNCLASSIFIED G B WRIGHT ET AL. JUN 87 F/G 9/1 NL



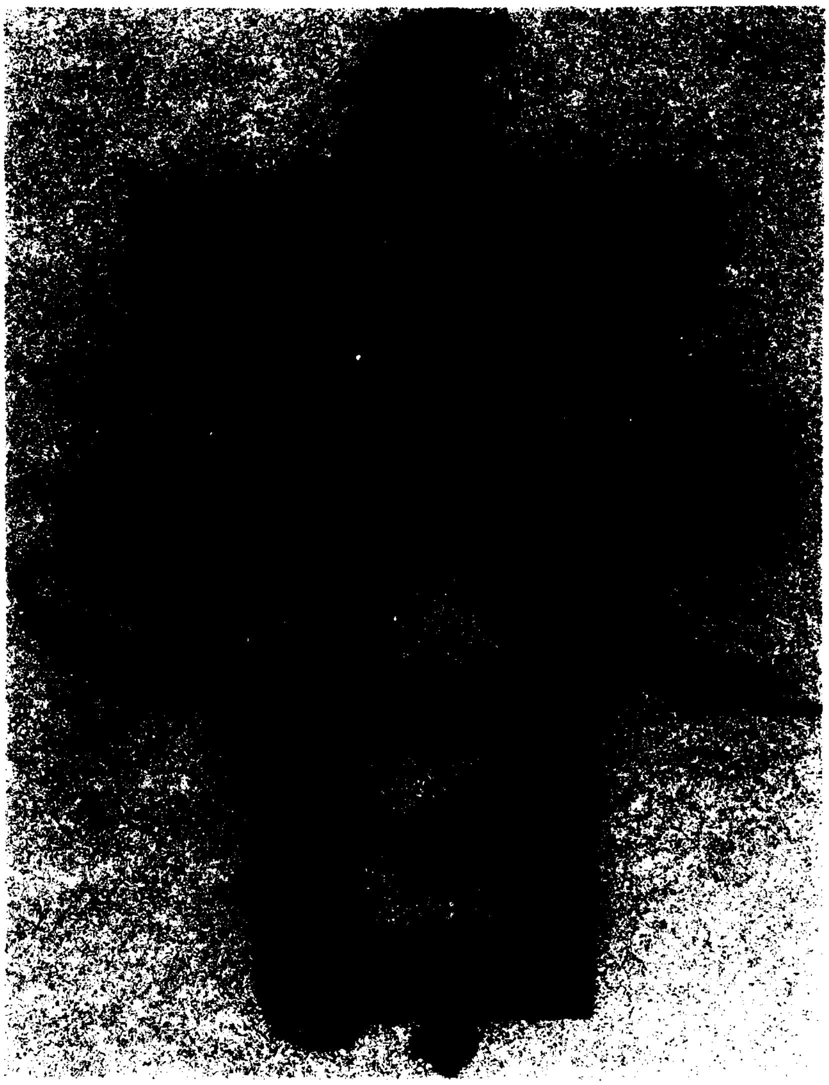
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APRIL TO JUNE 1987 DTIC FILE COPY VOL 12, NO. 2 (12)

SCIENTIFIC BULLETIN

DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH FAR EAST
DEPARTMENT OF THE AIR FORCE OFFICE OF SCIENTIFIC RESEARCH FAR EAST
UNITED STATES ARMY RESEARCH OFFICE FAR EAST

AD-A185 242



DTIC
ELECTE
SEP 2 4 1987
S D
A

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

NAVSO P-3580

87

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) ONRFE Vol 12, No. 2	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION ONR/AFOSR/ARO 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Liaison Office, Far East APO San Francisco 96503-0007	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
ONR FAR EAST SCIENTIFIC BULLETIN

12. PERSONAL AUTHOR(S)
George B. Wright, Director; Sandy Kawano, Editor

13a. TYPE OF REPORT	13b. TIME COVERED FROM ____ TO ____	14. DATE OF REPORT (Year, Month, Day) April-June 1987	15. PAGE COUNT

16. SUPPLEMENTARY NOTATION

ISSN: 0271-7077

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Superconductors	Superconductivity theory	Ceramics
			Perovskites	Polymetallic metals	India
			Japan	Antarctic research	Semiconductors

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONR Far East, the Air Force Office of Scientific Research, and the Army Research Office, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest.

Subscription requests to the Scientific Bulletin should be directed to the Superintendent of Documents, Attn: Subscription, Government Printing Office, Washington, DC 20402. The annual subscription charge is: domestic, $13.00; foreign, $16.25. Cost for a single copy is: domestic, $4.50; foreign, $5.65.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION	
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

18. Subject Terms (Key Words) continued

High transition temperatures
Indian Department of Ocean Development
Marine science and technology
People's Republic of China
Integrated circuit technology
Silicon-on-insulator technologies
Nickel electrode multilayer capacitors
Carbon fiber reinforced cement
Tensile behavior of CFRC
Optoelectronic integrated circuits
Transverse flow CO_2 lasers
Optoelectronics Joint Research Laboratory
Focussed ion beam implantation
Epitaxial crystal growth
Applied surface physics
Laser surface hardening
Wave devouring propulsion
Convective heat transfer
Propeller-hull interaction
Propeller-rudder interaction
Effective wake prediction
Ship hydrodynamics research
Doping techniques
Silicon materials
Thin film technology
Amorphous silicon
Free-surface effects
Electronic films
Barium titanate analysis
Anisotropic materials
Piezoelectric transducers
Heat transfer
Electric fields
Radar
Radar imaging
Radar identification
Magnetohydrodynamics
Surface tension effects
Construction materials
Laser processing
CO lasers
Laser cutting
Bulk crystal growth

Portial contents:

CONTENTS

QUALITY INSPECTED 2

Accession For
NTIS GRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification

By
Distribution/
Availability Codes
Avail and/or
Dist Special
A-1 24

(cont)

This issue features "Spring," the second in a series of four Katazome (stencil dyeing) prints from Kichiemon Okamura's "Four Seasons," an expressive rendering of Kanji characters depicting each season of the year.

HIGH T_c SUPERCONDUCTORS IN JAPAN

George B. Wright

Japan is a major contributor to the new wave of research on high T_c oxide superconductors. In this overview some tutorial material is provided on the perovskite crystal structure to which the new compounds are related. Based on the structural identifications of the new phases, a discussion is given of what may be expected in future developments, and a tabulation is given of some of the important groups contributing to the research in Japan.

INTRODUCTION

The discovery of high transition temperature oxide superconductors is creating the greatest wave of scientific interest since the announcement of the transistor, and this time the game is international, with players in Europe, the United States, Japan, China, and India. Japanese researchers are leading contributors, with the first confirmation of the initial reports from Switzerland, and more importantly, the identification of the actual material and crystal structure responsible for the superconductivity. Of course the excitement is caused by the enormous potential for applications foreseen (and unforeseen) which are made possible by transition temperatures well above the boiling point of liquid nitrogen. Anything electrical is thought to be fair game, with transportation, electrical power, computers, and communication leading the list. When we realize that these items form the core of our modern high-tech society, we understand that in fact it is difficult to imagine the importance of the achievement.

The international firestorm of excitement can be dated from Professor Kohichi Kitazawa's announcement at the Boston Materials Research Society Meeting (Dec 1986) of identification of the superconducting phase. As research groups all over the world mobilized to work on the new materials, information began to flow at such a rate that the normal channels of communication, the professional society journals, were soon saturated, and accounts of new accomplishments began to be announced in the popular press and on television. In the United States, an American Physical Society meeting in New York produced a crowd that could not be accommodated, and the meeting was teleconferenced to Japan. Similar meetings were held in Japan for the Physical Society of Japan in Nagoya and the Applied Physics Society in Tokyo. The initial flood of information was difficult to digest, but now perhaps it is a little more tractable. In this hope, we are presenting an initial short overview, with some tutorial material, and in succeeding issues plan to cover in more detail the work of leading research groups in our geographical area.

PEROVSKITES

The new oxide superconductors identified to date crystallize in structures related to the Perovskite structure. My first assignment as a new graduate student in Professor A.R. von Hippel's Laboratory for Insulation Research at MIT was to grow barium titanate crystals under the direction of Dr. Alexander Smakula. Barium titanate is a perovskite and is

important as a ferroelectric. Along with a lot of good science, kindly Dr. Smakula also taught me some important life-truths, among which was the advice that when you are presenting new material, it should be well lubricated with things your audience already knows. With this in mind, I show in Figure 1 a drawing of the unit cell for the Perovskite structure, which has chemical composition ABC_3. Crystals of interest will have oxygen at position C, copper at position B, and yttrium or barium at position A. If we form a sandwich of three cells, as shown in Figure 2, with yttrium in the central cell, and barium above and below, we would obtain a perovskite-related structure with composition $YBa_2Cu_3O_9$. This is not the superconducting material, but if we remove oxygen at the cube edges as indicated by the open squares in Figure 2, we obtain the structure believed responsible for the transition temperature of about 90 K. The composition with these removed oxygens is $YBa_2Cu_3O_7$, and the crystal is rhombohedral, with vacancies lined up along the b-axis. It is possible to further reduce the crystal by removing oxygen at the positions indicated by the black squares. The composition of this structure is $YBa_2Cu_3O_6$; this crystal has tetragonal symmetry, and it is not superconducting. By heat treatment in the appropriate atmosphere, it is possible to vary the composition over a wide range between these two phases, which is why we see formulas like $YBa_2Cu_3O_{7-x}$.

An easily accessible source for physicists who wish to read more about perovskites is W.A. Harrison's text (*Electronic Structure and the Properties of Solids*, W.H. Freeman & Co., San Francisco, 1980), which gives a lucid description of their electronic structure and other properties. In this issue of the *Scientific Bulletin* we are also fortunate to have a contribution from Dr. John B. Goodenough, who brings to the subject more than two decades of outstanding research on the perovskites. His 1971 review article in Volume 5 of *Progress in Solids State Chemistry* is considered a classic. He discusses the structure and chemistry of the crystals mentioned above in some detail and gives us his thoughts on the parameters of superconductivity.

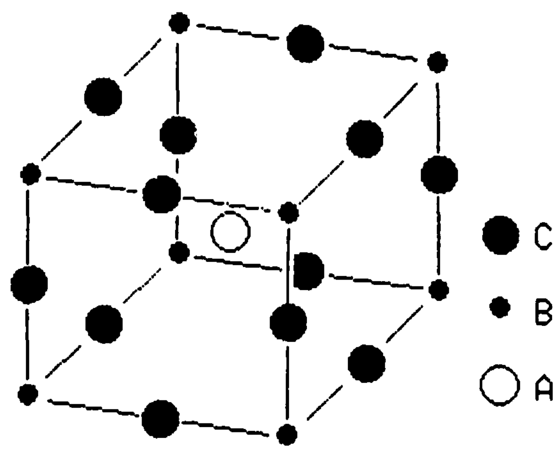


Figure 1. Perovskite structure of an ABC_3 compound.

In an outstanding publishing accomplishment, the editors of the English language *Japanese Journal of Applied Physics Letters* have presented an enormous number of papers by Japanese researchers on the new materials. These comprise special sections of the April and May issues of Volume 26, 1987. Scanning these volumes reveals that most of the papers in the April issue discuss the lanthanum based compounds with transition temperatures around 40 K, while the May issue papers are mostly about the yttrium based compounds, with transition temperatures above 90 K.

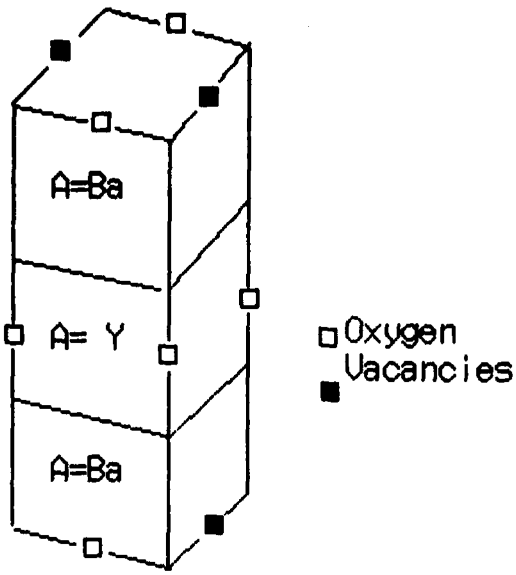


Figure 2. Structure of $YBa_2Cu_3O_7$ and $YBa_2Cu_3O_6$. The black-filled vacancies create the O_6 structure from the O_7.

Having the identity of the two crystal structures of oxides which provide transition temperatures T_C around 40 K and around 90 K is very helpful in organizing our thoughts about what may happen next and what is important.

- First, it seems that the transition temperatures depend heavily on crystal structure and, to some extent, less on the exact occupants of the sites, with the exception of copper and oxygen. A great number of chemical substitutions have been explored, with only secondary effect on T_C (some substitutions destroy the superconductivity).

- A corollary of this is that one probably has to find a new structure to get any great increase in T_C, so many workers will be attempting to do this. The oxygen-copper configurations have some common points in the two presently known structures, so it will be interesting to see whether there exist additional similar structures in the phase diagram that have different superconducting properties. Exploration of this phase diagram space is a demanding but finite task, and we can expect that it will be accomplished.

- We can expect that a great host of experiments will be performed to physically characterize the new crystals. An army of workers world wide have turned their talents to this task. They will provide the information necessary to support theoretical models of the mechanism for superconductivity, which is very likely not to be the phonon-mediated BCS mechanism operable in all other hitherto known superconductors. Explication of the mechanism will be of very great intellectual importance, but it remains to be seen what impact it will have on practical developments. This importance will probably depend on the application.

- A great scramble for patents on practical applications is underway, with rumors that some organizations have several hundred applications submitted already. It is possible that the viability of the patent system might be tested. Early applications will be superconducting wires and cables and superconducting electronics. Critical current carrying capabilities, critical magnetic fields, and, for electronics, uniformity of product are important. The present oxides are thought vulnerable to chemical deterioration.

An interesting aspect of competition to capture the superconducting wire market was pointed out to me by Professor Kent Bowen during his recent visit here. Japanese firms already making wire from conventional superconductors include Mitsubishi Electric, Hitachi, Sumitomo Electric, Kobe Steel, Fujikura, and Toshiba-Showa Denki (joint). Comparisons of assets and experience with firms elsewhere seem a case of Snow White and the Seven Giants. Will the commercial superconducting wire Olympics be run entirely in Japan?

It seems appropriate to close this brief account with a story about amateur participation in superconductivity fever in Japan. The editorial staff at the *Asahi Weekly Magazine*, while reporting for popular consumption on the new development in superconducting materials, decided to try their own hands at making some. They went out with a budget of ¥51,000 (about $350) and bought yttrium oxide, barium carbonate, and copper oxide; a hobbyist jewelry furnace; mortar and pestle; digital voltmeters; thermocouples; and a container of liquid nitrogen. The high cost items were the furnace and the digital voltmeters. In the magazine office, they ground the materials together and fired them twice following advice from Professor Shinobu Hikami of Tokyo University's College of Arts and Sciences. They then prepared a sample for four probe resistance measurements and, using the digital voltmeters, recorded a beautiful current voltage curve. They obtained a sharp transition around 90 K. An account of the work was published in the magazine article on superconductivity, and the curve looked pretty state-of-the-art. Someone told me it's almost impossible to buy a mortar and pestle these days in Japan because everybody is doing superconductivity research on their own.

A partial list of some of the important research groups working on superconductivity in Japan is in the Appendix.

George B. Wright, director of ONR/AFOSR/ARO Far East from August 1985, has been program director of solid state physics and physical electronics at ONR since 1978. From 1958 to 1972 he did research at MIT Lincoln Laboratory on optical and electronic properties of semiconductors, and from 1972 to 1978 he was Batchelor Professor of Electrical Engineering and Professor of Physics at Stevens Institute of Technology. His research interests include the relation between electronic structure and properties of solids and microscopics of materials processing for electronic devices. Dr. Wright is a Fellow of the American Physical Society and a member of the IEEE.

Appendix

HIGH T_c SUPERCONDUCTOR RESEARCH GROUPS IN JAPAN

University of Tokyo

Dept. of Applied Physics
Professor Shohji Tanaka
Lecturer Shinichi Uchida

Dept. of Industrial Chemistry
Professor Kazuo Fueki
Assoc. Prof. Kohichi Kitazawa
Assoc. Prof. Hideomi Koinuma
Kohji Kishio
Tetsuya Hasegawa

Engineering Research Institute, Faculty of Engineering
Assistant Hidenori Takagi

Institute for Solid State Physics
Professor Hidetoshi Fukuyama
Professor Nobu Mohri
Assoc. Prof. Masayasu Ichikawa
Assoc. Prof. Noboru Miura

College of Arts and Sciences
Assoc. Prof. Shinobu Hikami
Assoc. Prof. Seiichi Kagoshima

Hiroshima University
Professor Toshizo Fujita

Tokai University

Dept. of Physics
Sadao Nakajima

Tohoku University

Research Institute for Iron, Steel and Other Metals
Professor Masashi Tachiki
Professor Yoshio Muto
Assoc. Prof. Tsuyoshi Masumoto
Assoc. Prof. Yoshitami Saito

Institute for Molecular Science
Assoc. Prof. Masatoshi Sato
Research Assoc. Shouchi Hosoya

Electrotechnical Laboratory
Electronic Refractory Materials Section
Hideo Ihara
Cryogenic Engineering Section
Yoichi Kimura
Superconductor Research Group
Materials Division
Shigeru Maekawa

National Research Institute for Metals
Special Function Materials, Meguro
Keiichi Ogawa
Tsukuba
Kyoji Tachikawa
Superconducting and Cryogenic Materials, Tsukuba
Kazumasa Togano

National Institute for Research in Inorganic Materials

SUPERCONDUCTIVITY FEVER IN JAPAN

John B. Goodenough

The discovery of a superconducting transition above 30 K in a ceramic material has sparked an international race to explore and exploit this new class of superconductors and to understand the origins and limits of the higher superconducting transition temperature. This article discusses the superconductivity research of various Japanese groups and summarizes the experimental situation to date.

A Christmas card in December 1986 from M. Takano of Kyoto University stated tersely that the high point of his trip to Europe that summer had been a visit to the IBM Research Laboratory in Zürich where he had learned that Bednorz and Müller had in press (Bednorz and Müller, 1986) evidence of a superconducting transition above 30 K in a multiphase La–Ba–Cu–O mixture.

What made this observation exceptional was the widely held prejudice that the upper limit for a superconducting transition temperature, T_s, would be about 25 to 30 K. Superconductivity is a manifestation of the condensation of electrons (fermions obeying Fermi–Dirac statistics) into paired–electron units (bosons obeying Bose–Einstein statistics) known as Cooper pairs. A Cooper pair consists of two spin–paired electrons having momentum vectors +k and –k relative to a common center–of–mass momentum. In the Bardeen–Cooper–Schrieffer (BCS) theory of superconductivity, the pair potential coupling the electrons into a boson particle is phonon–mediated; a lattice deformation associated with one electron attracts the second electron of the pair. The net attractive potential is:

$$V_{BCS} = V_c - U$$

where V_c is the attractive potential and U is the coulombic electrostatic repulsion between the two electrons of a pair. According to this theory, the superconducting transition temperature varies as:

$$T_s \sim \theta_D \exp[-1/N(0)V_{BCS}] \quad (1)$$

where θ_D is the Debye temperature characteristic of the highest vibrational frequency of the atoms and N(0) is the density of one–electron states at the Fermi energy at the absolute zero of temperature (T = 0 K). In the absence of any precise translation of V_c into real–space parameters, attention focused on the density–of–states term N(0) in the semiempirical search for higher T_s superconductors.

Two decades of searching had encountered an experimental barrier at about $T_s \leq 23$ K; materials designed to have a high N(0) were plagued by lattice instabilities, and it became an accepted wisdom that the formation of a charge–density–wave (CDW) state would quench out the superconducting state where N(0) became high enough to give a $T_s > 30$ K. Therefore, the existence of a superconductor having a $T_s > 30$ K would command a reevaluation of the theory.

A second remarkable feature of the observation was its occurrence in a ceramic material. Since superconductivity is a state exhibiting zero electrical resistance, the oxides—most of which are insulators—were not an obvious place to look for high-temperature superconductivity. However, many oxides are good electronic conductors. Compounds having mixed formal cationic valences on crystallographically equivalent (hence energetically equivalent) lattice sites, as in the inverse spinel magnetite $Fe^{3+}[Fe^{2+}Fe^{3+}]O_4$ or the metallic tungsten bronze Na_xWO_3, and the so-called interstitial oxides such as metallic TiO have long been known. Indeed, TiO and the spinel $Li[Ti_2]O_4$ are superconductors, and the theoretical basis for metallic oxides has been established (Goodenough, 1971).

Probably the first groups to respond to the work of Bednorz and Müller with a crash program were at the University of Tokyo. Professor Shohji Tanaka of the Department of Applied Physics and Professor Kazuo Fueki of the Department of Industrial Chemistry, together with their associates, formed an interdisciplinary team experienced in the chemical and structural characterization of mixed-metal oxides and in the measurement of superconducting properties. By late autumn they had identified the superconducting phase of the Bednorz-Müller mixture as having the tetragonal K_2NiF_4 structure at room temperature and a composition $La_{2-x}Ba_xCuO_{4-y}$ (Uchida et al., 1987; and Takagi et al., 1987). They reported this finding in international meetings in India and in Boston, MA, in November. Confirmation of the superconducting transition at a $T_s > 30$ K and identification of the phase stimulated groups in the rest of the world into a similar activity, and by Christmas of 1986 it was clear that an international race was on to explore and exploit this new class of superconductors and to understand the origins and limits of the higher T_s.

The immediate strategies were straightforward: substitute Sr^{2+} or Ca^{2+} for the Ba^{2+} ion, substitute rare-earth ions or Y^{3+} for the La^{3+} ion, and retain copper in a high $(Cu^{3+,2+})$ formal oxidation state by keeping the sintering temperature as low as possible and annealing under oxygen at a low temperature (400 to 600 °C). In order to avoid disruption of the Cooper pairs by a localized atomic moment on the rare-earth atoms, the first substitutions for La^{3+} would be Y^{3+} and Lu^{3+}.

By January, several groups in the U.S. and the group in Tokyo were reporting transition temperatures $T_s \geqq 40$ K in the system $La_{2-x}Sr_xCuO_{4-y}$ with a maximum near $x \simeq 0.15$. This led to speculation in Tokyo of a critical Cu-O distance for high T_s, and a group led by C.W. Chu in Houston, TX—adding hydrostatic pressure as a variable—reported an extraordinary pressure sensitivity of T_s (Chu et al., 1987).

By February, the first reports of a $T_s \simeq 90$ K in a Ba-Y-Cu-O multiphase mixture were being announced in the press from at least three countries, including the group in Japan. Substitution of Y^{3+} for La^{3+} in the $La_{2-x}Ba_xCuO_{4-y}$ phase had been tried without success, but it had led to the accidental discovery of a new superconducting phase with a $T_s > 77$ K. This fact and the scramble for credits in the public news media alerted everyone that a discovery of great technical potential had been made, and industrial teams were assembled all over the world to learn how to fabricate these brittle ceramics into wires and films for technical applications.

In March, at an extraordinary session of the Applied Physics Society meeting in New York City, several groups were reporting identification of the new phase as $YBa_2Cu_3O_{7\pm y}$. In the same week, announcement of the structure of the cation array and the fact that it is not variable within the Y-Ba-Cu-O phase diagram were also being reported at the American Crystallographic Society meeting in Austin, TX. Identification was done independently in Bangalore, India, and by the group at the University of Tokyo. However, pinning down with certainty the oxygen positions in the new phase awaited neutron-diffraction experiments as single-crystal specimens were not available; moreover, it was clear that the oxygen content depended critically on the preparative conditions.

By the end of April, Swinnea and Steinfink (n.d.) at Austin, TX, had identified by single-crystal x-ray diffraction the structure of a tetragonal $YBa_2Cu_3O_{6+x}$ ($x < 0.2$) phase that is essentially isostructural with the orthorhombic superconducting phase except for a disordering of oxygen vacancies in one plane of the structure. Our Austin group had also probed by thermal analysis the $YBa_2Cu_3O_{7-y}$, $0 < y < 1$, phase diagram. Conversations with research workers at the University of Tokyo and the University of Kyoto at the IUPAC CHEMRAWN VI conference in Tokyo, held 17-22 May, revealed that similar results had been obtained in Japan and were about to be submitted for publication.

The experimental situation as of the time of the CHEMRAWN VI conference may be summarized as follows:

- The system $La_{2-x}Sr_xCuO_{4-y}$ has the tetragonal structure (for $x \geq 0.05$) of Figure 1, and a maximum $T_S \simeq 43$ K occurs for $x \simeq 0.12$–0.15 and $y \simeq 0$. The normal conductivity above T_S is poor—it is at the threshold of a transition from polaronic to itinerant-electron behavior—and highly anisotropic; the electronic conductivity is confined to the Cu-O layers, and interlayer charge transfer is much weaker than intralayer charge transfer. Moreover, N(0) is not particularly large.

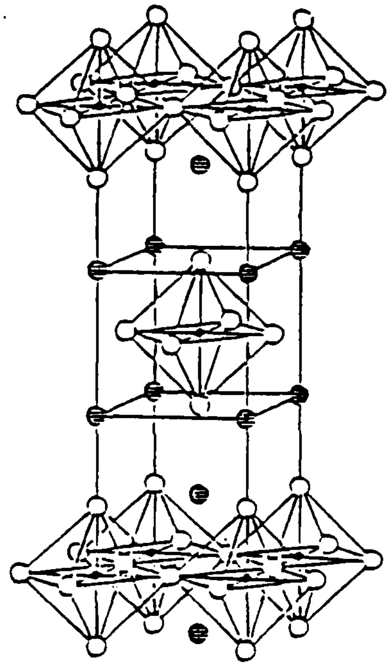


Figure 1. The tetragonal K_2NiF_4 structure. In $La_{2-x}Sr_xCuO_{4-y}$, the copper (dark circles) occupy octahedral sites that are strongly distorted to tetragonal (c/a > 1) symmetry, which emphasizes the two-dimensional character of the Cu-$\sigma^*_{x^2-y^2}$ conduction band.

- The system $YBa_2Cu_3O_{7-y}$, $0 < y < 1$, contains two phases: the orthorhombic structure of Figure 2 exists over the range $0.05 \leq y < y_C$, where $0.3 < y_C < 0.5$ is yet to be pinned down precisely, and the tetragonal structure of Figure 3 exists for $0.8 < y < 1.0$. The orthorhombic phase is superconducting, reaching a $T_S \approx 93$ K as $y \rightarrow 0$; the tetragonal phase is not. A two-phase region exists in the interval $y_C < y \leq 0.8$. It is possible to convert from $y > 0.8$ to $y \approx 0.05$ by annealing in O_2 at 350 to 400 °C. The topotactic insertion/extraction of oxygen is rapid at 400 °C, and oxygen loss occurs continuously with increasing temperature or decreasing oxygen pressure. Moreover, the phase is readily attacked by water vapor.

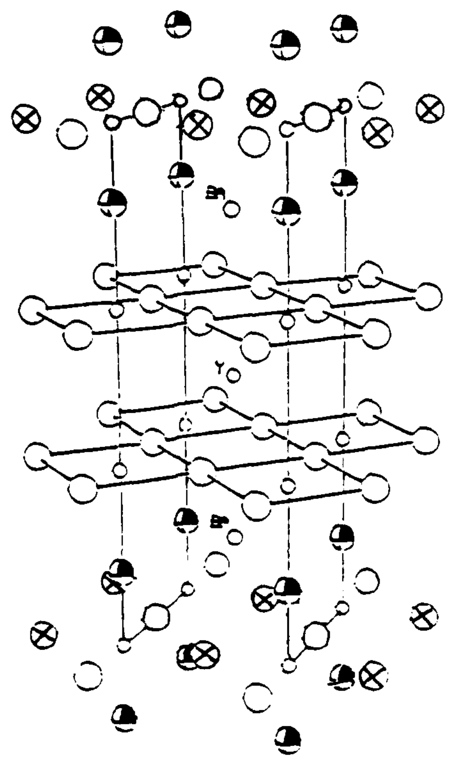


Figure 2. The structure of the fully oxidized, orthorhombic, superconducting phase $YBa_2Cu_3O_7$. In this structure, oxygen vacancies (shown with crosses) are accommodated at the b-axis bridging-oxygen positions of the $(CuO_3)^{3-}$ chains.

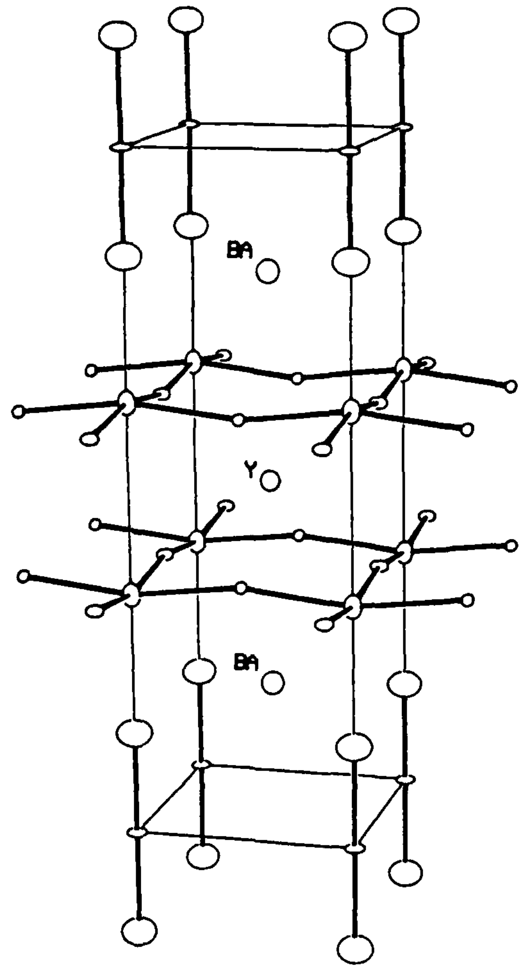


Figure 3. The structure of the fully reduced, tetragonal, nonsuperconducting phase $YBa_2Cu_3O_6$.

- Superconducting films and wires of $YBa_2Cu_3O_{7-y}$ have been fabricated. The intrinsic critical current of the material is comparable to that of other superconductors, but polycrystalline bars, films, or wires tend to have critical currents some two orders of magnitude lower as a result of normal-conductor layers at the grain boundaries.

- A small coherence length ($\xi \approx 25$ to 40 Å) indicates that the use of these superconductors in Josephson-junction devices will be difficult, an anisotropic sensitivity of T_s to applied magnetic fields complicates their application at 77 K in high-field magnets, and the intrinsic chemical instabilities promise to make difficult the processing of these materials. Consequently, there is strong motivation to explore further this class of oxides for higher T_s materials with more convenient properties.

Meanwhile, the theorists have been put into an excited state. Figure 4 illustrates the highest known T_s as a function of time. After the discovery of superconductivity in Hg at 4 K by Kamerlingh-Onnes in 1911, T_s increased by about 3 °C/decade until it reached an apparent barrier at 23 K in the alloy Nb_3Ge. Ternary compounds such as $Li[Ti_2]O_4$ and $PbMo_6S_8$ were found with a $T_s > 10$ K and interesting critical fields, but there was no hint before the summer of 1986 that the BCS prediction of a $T_s(max) \approx 30$ K would be breached.

The extraordinary events since January of 1987 indicate that the new materials may require an alternate mechanism for Cooper-pair formation; and with the theorists in disarray, the experimentalists are in full cry with hopes rekindled of finding room-temperature superconductivity. These hopes have been fueled by reports from Berkeley, Wayne State, and other centers, of resistivity anomalies at temperatures as high as 240 K that could indicate some new superconducting phase. But these reports only manifest the superconductor fever that has swept the solid-state community; there is little reason to believe that another "find" similar to that of $YBa_2Cu_3O_{7-y}$ has yet occurred.

Numerous suggestions have been put forward to account for an enhanced T_s. P.W. Anderson, for example, suggests a "resonating antiferromagnetic coupling" among primarily 3d-state Cu-O antibonding electrons at formally Cu(II) ions of a Cu(III/II) σ^*-antibonding "3d" band. At CHEMRAWN VI, C.N.R. Rao of Bangalore, India, advocated resonating "2p" bonding à la Anderson, but associated with holes in the O^{2-}-$2p^6$ bands. Others, including T.M. Rice and coworkers in Switzerland, have argued for bipolaron formation due to coupling of the Cu(II) σ^*-antibonding 3d electrons to "breathing modes" of the oxide-ion array, charge fluctuations associated with a mixed-valence state presumably suppressing formation of a CDW, even an incommensurate CDW. In all these cases, the Cooper-pair formation is stabilized by an electron-lattice interaction, but the strength of this interaction allows the Cooper pair to be visualized within real space. However, aside from a general discussion by Nasu (1987), no attempt has been made to justify why, in the copper oxides, a CDW state should not compete with such superconducting states; more tellingly, experiments with ^{16}O and ^{18}O from Bell Telephone Laboratories have been reported to exhibit no isotope effect, which would seem to rule out Cooper-pair formation by strong electron-phonon interactions.

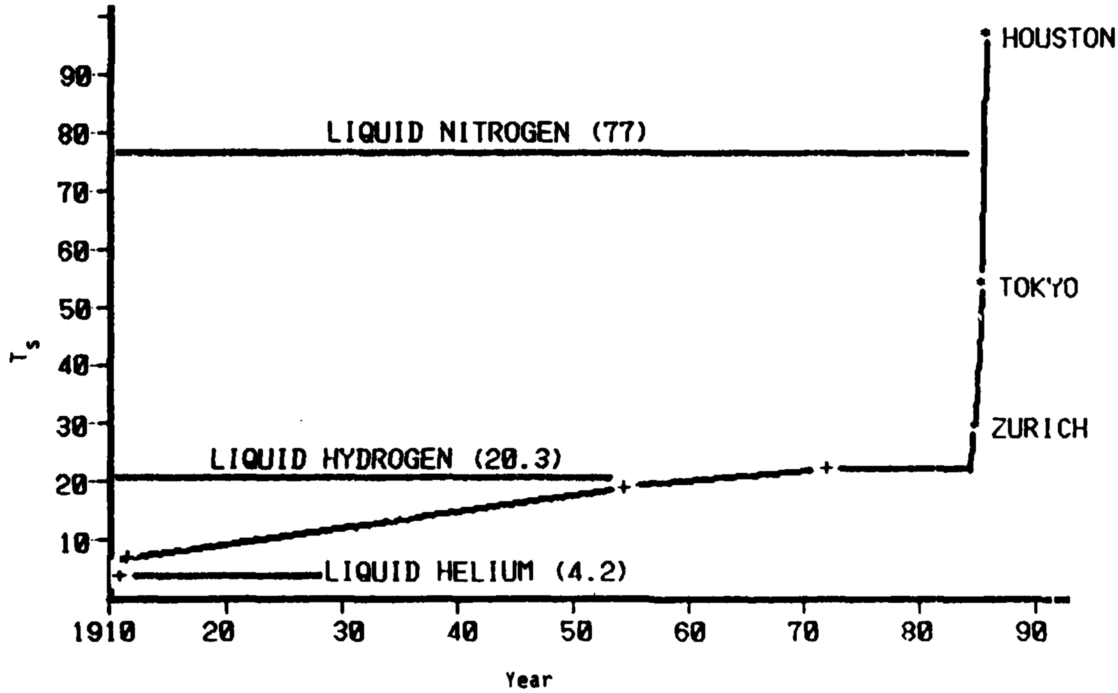


Figure 4. Highest known T_S versus the year of discovery.

An alternate coupling model has been championed by Ginsburg (1970) and discussed by Allender et al. (1973) in connection with the specific model of a thin (~10 Å) metallic layer on a semiconductor surface. In this model, metallic electrons at the Fermi surface tunnel into the semiconductor gap where they interact with virtual excitons within the semiconductor. This "exciton mechanism" is the only proposal in the literature known to us that does not require an associated isotope effect.

In this connection, another important experimental observation has been made by the Tokyo group, by the IBM group, the Chinese group, and others:

- Substitution for Y^{3+} of a lanthanide Ln^{3+} having a large atomic *magnetic moment* (e.g., Gd^{3+} with a moment of 7 μ_B) does not alter T_S in $LnBa_2Cu_3O_{7-y}$ phases.

This observation indicates that the superconductivity of the $YBa_2Cu_3O_{7-y}$ orthorhombic phase (Figure 2) is confined to the $(CuO_{3-y})^{3-}$ layers lying between Ba^{2+}-ion layers; local charge neutrality dictates that the CuO_2 layers either side of Y^{3+} or Ln^{3+} layers are formally $(CuO_2)^{2-}$. Thus, the structure appears to consist of "metallic" $(CuO_{3-y})^{3-}$ layers sandwiched between semiconducting Ba-CuO_2-Y-CuO_2-Ba layers having a small (correlation splitting) energy gap

like that in CuO and La_2CuO_4. (Some have argued that La_2CuO_4 is a semiconductor because of a CDW associated with cooperative motions of the basal-plane oxygen that make nearest-neighbor Cu distinguishable, but structural evidence for this model is still lacking.) Similarly, the rocksalt layers of the $La_{2-x}Sr_xCuO_{4-y}$ structure (Figure 1) would represent a semiconductor intergrowth between "metallic" Cu-O layers. Certainly intergrowths of metallic and semiconducting layers would seem to offer the best opportunity to attain an "exciton mechanism" for Cooper-pair formation, but the large energy gap of a $La_{2-x}Sr_xO_2$ rocksalt layer would seem to be incompatible with a mechanism that requires a semiconductor-gap frequency smaller than the plasma frequency of the semiconducting layer.

Particularly puzzling is the fact that the $(CuO_{3-y})3-$ layers of the $YBa_2Cu_3O_{7-y}$ structure (Figure 2) consist of linear chains of corner-shared, square-coplanar CuO_4 configurations for $y = 0$; a $y > 0$ implies the breaking of at least some of these chains since—as can be seen from a comparison of Figures 2 and 3—the oxygen vacancies are at bridging positions along the chain axis. It has yet to be determined whether the oxygen vacancies in the orthorhombic $YBa_2Cu_3O_{7-y}$ phase ($y > 0$) order into specific chains, leaving some chains intact, or whether they are randomly distributed in the a-b plane among all the b-axis chains.

In my view, the essential feature to be stressed in both the $La_{2-x}Sr_xCuO_{4-y}$ and $YBa_2Cu_3O_{7-y}$ phases is the position of the Fermi level relative to the top of the O^{2-}-$2p^6$ bands. A $Cu^{3+/2+}$ redox couple has an energy that lies below the top of O-p_π bands associated with the p orbitals oriented normal to a Cu-O plane. This fact means that oxidation beyond a formal valence Cu(II) of a Cu-O chain in Figure 2, or a layer in Figure 1, drops the Fermi energy into the O-p_π bands as well as into the Cu(III/II) redox band. In such a case, the concept of formal valence loses its meaning; instead there is a formal-valence equilibrium

$$Cu^{3+} + O^{2-} \rightleftharpoons Cu^{2+} + O^{-} \qquad (2)$$

associated with a charge transfer between the σ^*-antibonding "3d" states and the π-bonding "p" states. This situation is analogous to an "intermediate-valence" configuration as found in high-pressure SmS, where the Fermi energy intersects simultaneously a narrow 4f band and a broader 5d band. In the case of "intermediate valence" on the rare-earth ion, hybridization occurs between 5d and 4f orbitals of the same atoms. In the high-T_s copper oxides, on the other hand, the "O-p_π" and "Cu-σ^*" orbitals are not only orthogonal to one another, but are also primarily associated with different atomic arrays. In this case, stabilization of occupied states at the expense of unoccupied states may occur via an electrostatic attraction between a "Cu-σ^*" electron and an "O-p_π" hole. In such a coupling, the electron density uncovered by the O-p_π hole would have its momentum $-k$ relative to a $+k$ on the Cu-σ^* electron and a spin antiparallel to the Cu-σ^* electron; on the other hand, the electron-electron electrostatic interactions would stabilize, via direct exchange between spins in orthogonal orbitals, a ferromagnetic coupling. In the absence of any spontaneous magnetism of the σ^*-band electrons, formation of a spin-paired boson would be the more stable configuration. Since Cooper-pair formation is mediated, in such a model, by electrostatic forces

rather than electron–lattice interactions, it is not quenched by competition from lattice instabilities associated with formation of a CDW; moreover, T_s need not exhibit an isotope effect.

The model proposed above has quite stringent constraints. If electron-hole attraction stabilizes at high T_s the condensation of bosons via a shift in the relative strengths of the Cu–O σ and π bonding, then the following set of specifications must be satisfied in any other high-T_s superconducting oxides:

- An unusually high oxidation state should place the Fermi energy within overlapping O–p_π and narrow transition-metal d bands. Stabilization of such a high oxidation state may require a strongly basic counter cation like Ba or Sr.
- The narrow d band should be at the threshold of polaronic versus itinerant-electron behavior so as to allow formation of a relatively small-volume boson.
- There should be no spontaneous atomic moment associated with the transition-metal atoms responsible for the narrow bands.
- The coupling should occur between a planar σ^*-antibonding electron and a p_π-bonding hole associated with p_π orbitals normal to the strongly bonded plane.

Such a set of constraints is not easy to satisfy, which could be the reason that high-T_s superconductivity has thus far been found only in oxides containing highly oxidized copper.

These final personal ideas are offered in response to the repeated queries about appropriate experimental strategies that I have received from Japanese chemists who are busily mixing oxides in the many laboratories of Japan now infected by superconductivity fever, an infection picked up in Switzerland and spread from Tokyo to the solid-state community throughout the world.

REFERENCES

Allender, D., J. Bray, and J. Bardeen. 1973. *Phys. Rev.* B7:1020.

Bednorz, J.G., and K.A. Müller. 1986. *Z. Phys.* B64:189.

Chu, C.W., P.H. Hor, R.L. Meng, L. Gao, Z.J. Huang, and Y.Q. Wang. 1987. *Phys. Rev. Lett.* 58:405.

Ginsburg, V.L. 1970. *Usp. Fiz. Nauk* 101:185.

Goodenough, J.B. 1971. *Prog. Solid State Chem.* 5, chap. 4.

Nasu, K. 1987. *Phys. Rev.* B35:1748.

Swinnea, J.S., and H. Steinfink. n.d. *J. Mat. Res.* In press.

Takagi, H., S. Uchida, K. Kitazawa, and S. Tanaka. 1987. *Jpn. J. Appl. Phys.* 26(2).

Uchida, S., H. Takagi, K. Kitazawa, and S. Tanaka. 1987. *Jpn. J. Appl. Phys.* 26(L1).

John B. Goodenough took up the Virginia H. Cockrell Chair of Engineering, Center for Materials Science and Engineering, University of Texas at Austin, Austin, TX, in September 1986 after 10 years as Head and Professor of Inorganic Chemistry, University of Oxford, England. While at Lincoln Laboratory, MIT, from 1952–1976, he studied the evolution from magnetic insulators to metallic behavior in transition-metal oxides, and his pioneering work laid a fundamental basis for our description of the oxides exhibiting high-temperature superconductivity.

THE INDIAN DEPARTMENT OF OCEAN DEVELOPMENT

Wayne V. Burt

The Indian Department of Ocean Development supports a variety of different projects for all types of marine science and technology and Antarctic research. Some of the programs it is funding include surveys of the living and nonliving resources in the waters off the coasts of India, a search for polymetallic metals from nodules on the seafloor, desalination of brackish water, the distribution of ozone in the air over the Antarctic, and extraction of energy from the oceans.

INTRODUCTION

The Indian Department of Ocean Development (DOD) was established as a part of the Ministry of Science and Technology in 1981. Since that time, it has grown very rapidly. It now has a staff of 100 and a current annual budget of $22 million. It is the largest source of funding in India for all types of marine science and technology, as well as Antarctic, research. Although DOD does not directly operate any laboratories or institutes, it coordinates and provides funds for marine research and instruction in about 40 different institutes, institutions of higher education, and other organizations in the Indian government.

RESEARCH VESSELS

In 1983, DOD acquired the ocean research vessel *Sagar Kanya*, one of the most sophisticated and highly advanced research vessels in the world. The vessel, which was designed and built in West Germany, is equipped for all types of marine research. It is 100 meters long with a gross tonnage of 4,000. It has sleeping accommodations for 91 persons including 23 scientists and 8 technicians. The vessel is assigned to and operated by the National Institute of Oceanography in Goa, its home port. A second smaller fisheries and oceanographic research vessel, the *Sagar Sampada*, was built a year later. It was designed and built in Denmark and modelled after modern Danish trawlers. It is assigned to and is operated by the Central Marine Fisheries Research Institute in Cochin. Most of its research is carried out in India's Exclusive Economic Zone and contiguous continental shelf waters. The vessel is ice strengthened for research in the Antarctic as far south as 60° S. latitude. The annual operating costs for both of the above vessels are paid by DOD.

A search through the reports of the cruises that both vessels have made indicates that most of the cruises are multiple-purpose cruises. Usually, the scientific parties on cruises are from three or more government laboratories or universities.

The first primary objective for both of the research vessels has been a series of cruises to survey the living and nonliving resources (except petroleum) in the 200-mile Exclusive Economic Zone and continental shelf area off the coasts of India and to search for polymetallic nodules on the deep ocean floor of the central Indian Ocean south of India.

POLYMETALLIC METALS

India is making a serious effort to obtain strategic metals from nodules on the seafloor. Over 4 million km^2 of the ocean floor have been surveyed and the concentration of nodules mapped. In addition to using the *Sagar Kanya*, India has chartered one Norwegian and two

British ships to assist in the survey. Several governmental and industrial laboratories have been carrying out research to determine the kinds and concentrations of the various metals contained in samples of the nodules. Research is underway on methods for recovering the most abundant metals in the nodules. A small pilot extraction plant is in operation.

DOD is proposing to set up an autonomous corporation or commission to handle commercial exploitation of the mineral wealth of the ocean. Its primary purpose will be the exploration of seafloor nodules.

DESALINATION

The water available for human consumption in many parts of several coastal states in India is largely brackish. DOD has sponsored research on the use of reverse osmosis to desalinate brackish water. Two pilot plants are now in operation. They produce a total of 100,000 liters of potable water per day. One plant has been established near Madras in Tamil Nadu and the other in Andhra Pradesh.

EDUCATION AND TRAINING

At the present time, there are no national centers for training in marine science or technology in India. However, there are 30 academic and other training institutions in India that offer some courses in marine science. DOD is providing financial assistance to 100 students who are studying in these institutions. The present estimate is that about 3,500 people need to be trained in the various disciplines of marine science during the next 15 years.

ANTARCTIC RESEARCH

DOD has sent an expedition to the Antarctic each year since 1981. During the third expedition (1983-84), India established its first permanent Antarctic manned station, "Dakshin Gangotri" (South Ganges), at about 70°46' S. latitude and 12°05' E. longitude. Since that time, teams have been wintering over at the station. About 86 persons from 21 different Indian government agencies and educational institutions took part in last year's expedition (1985-86). The objectives of the expeditions are to carry out geophysical surveys and studies of geology, meteorology, biology, communications, glaciology, oceanography, and the environment. DOD is in the process of establishing an Antarctic Study Center in Goa.

At the present time (January 1987), India has a 90-member team at its Antarctic station. The latest year-round study is on the distribution of ozone in the air over the Antarctic. At certain times of the year, the ozone is somewhat depleted in a "hole" over the Antarctic. Because the ozone layer in the upper atmosphere is of vital importance in screening out most of the harmful ultraviolet radiation from the sun's rays, it is important to learn the mechanism by which the ozone is depleted.

ENERGY FROM THE OCEANS

All sources of energy are in short supply in India. A governmental planning commission has estimated that the need for electric power, coal, and petroleum products will increase from three to fivefold in the next 20 years. Hydroelectric power is one of the principal sources of power. However, its output varies from year to year depending on the unreliable amount of rainfall from the monsoons. For this reason, the Indian government is supporting a major research effort in the search for alternative renewable sources of energy that will not require increased imports of fossil fuel. DOD is supporting exploratory studies of all possible methods for extracting energy from the oceans.

Tide and current data are being collected in bays and estuaries to help determine whether it is feasible and cost effective to erect one or more tidal barrages in order to convert tidal energy into electrical power.

All aspects of the possibility of converting ocean wave energy into electrical power are under study. A wave rider buoy that has been deployed off the coast near Madras has collected a full year of wave data.

Since 1979, a consortium of university and industrial research centers has been studying the potential for ocean thermal energy conversion (OTEC). Similar studies in the United States, Japan, France, Sweden, and the Netherlands have indicated that OTEC may be the most promising source of large-scale recovery of usable energy from the oceans. A site study of Kavarati atoll has shown that it is a promising site for an OTEC installation. A temperature differential of 19 °C exists between the surface water and water at a depth of only 650 meters.

MARINE POLLUTION

Pollution of the marine environment along the coasts of India is not as great as it is around more heavily industrialized coastal nations; however, the marine environment is deteriorating, especially in the waters around the more heavily industrialized coastal cities such as Bombay, Madras, and Cochin. For this reason, DOD-supported ships collect environmental data regularly on all cruises. During the current 5-year plan, some 20 pollution monitoring stations are scheduled to be established at selected points along the coasts of India.

MANNED SUBMERSIBLE

DOD is in the process of finalizing a manned submersible that is expected to be in operation within a few years. It is being designed with an operating depth of 600 meters. It will be used for on-the-spot inspection of offshore installations and structures as well as geophysical, biological, and physical studies in coastal areas.

The Department of Ocean Development and its very dynamic secretary (head), Dr. S.Z. Qasim, have a most enviable and impressive record for cutting through red tape and avoiding bureaucratic slowdowns. It is hard to believe that the smooth running organization could have reached its high level of competence in the short time since its establishment. The address of DOD is Block 12, CGO Complex, Lodi Road, New Delhi-110003, India.

Wayne V. Burt received his Ph.D. from Scripps Institute of Oceanography in 1952 (UCLA). Dr. Burt was Science Attache for Oceanography and Meteorology in the American Embassy in New Delhi, India, from October 1986 to April 1987. Previously, he was a professor at Oregon State University and served as a liaison scientist of oceanography and meteorology for the Office of Naval Research, London, from 1979 to 1980. Dr. Burt's current interest is in air-sea interaction.

THE INTERNATIONAL CONFERENCE ON SEMICONDUCTOR AND INTEGRATED CIRCUIT TECHNOLOGY, BEIJING, CHINA

S. Ashok

The International Conference on Semiconductor and Integrated Circuit Technology, in Beijing, the People's Republic of China, served as an ideal forum for the exposition of Chinese accomplishments in the field. The conference covered all aspects of integrated circuit technology, encompassing areas as diverse as device physics, circuit design, material development, and fabrication technology. This article discusses the latest Chinese developments in the fields of selective doping techniques, silicon materials, thin film technology, amorphous silicon, and silicon-on-insulator technologies.

INTRODUCTION

The International Conference on Semiconductor and Integrated Circuit Technology was held at Xiang Shan (Fragrant Hill) Hotel in a northwest suburb of Beijing from 19-26 October 1986. It was held under the auspices of the Chinese Institute of Electronics, and the Department of Continuing Education in Engineering, University Extension, University of California, Berkeley. The first of its kind in scale and scope to be held in China, the conference attracted a wide audience of Chinese as well as overseas participants. While the international character of the meeting was evident from the large number of papers presented by technologists from overseas, the meeting served as an ideal forum for the exposition of Chinese accomplishments in the field. This article, based on the presentations of researchers from Chinese universities and research laboratories, is intended as a nonexhaustive overview of semiconductor-related activities in China. A list of the Chinese-contributed papers is in the Appendix.

The conference was intended to cover all aspects of integrated circuit technology, and so it encompassed areas as diverse as device physics, circuit design, material development, and fabrication technology. It was held in five parallel sessions grouped under the following main themes: patterning technology, selective doping techniques, silicon materials, rapid thermal annealing, thin film technology, amorphous silicon, superconductor electronics, advanced device technology, metal oxide semiconductor (MOS) and bipolar integrated circuit (IC) technology, circuit design, silicon-on-insulator technologies, yield/reliability, process characterization, materials characterization, and fab operations. This article explores the scope of Chinese research efforts in five of these areas.

SELECTIVE DOPING TECHNIQUES

This session contained papers dealing not only with doping but also with oxidation, nitridation, and ion implant modification of semiconductor surfaces. He Ziaoyin et al., of the

Institute of Microelectronics, Tsinghua University, Beijing, presented experimental results on charge trapping in thin oxides and the resultant wearout of electrically erasable programmable read only memories (EEPROM). From pulsed current-voltage measurements before and after electrical stress, they were able to evaluate the charge trapped in the tunnel oxide. These measurements then served as the basis for simulation of voltage shifts for the erase and write cycles.

The breakdown characteristics of ultrathin oxides (3 to 15 nm) were studied by Yang Buyi of the Wuxi Microelectronics Research Centre. Well-defined breakdown characteristics were seen for oxides thicker than 5 nm, with no significant dependence of dielectric strength on oxide thickness in this range. Post-oxidation anneal at 900 °C for up to 3 hours resulted in improved dielectric strength, particularly for oxides grown in dry oxygen.

Tsou Shihchang, of the Ion Beam Laboratory, Shanghai Institute of Metallurgy, presented a paper on ion implantation and laser recrystallization of GaAs and InP. Planar GaAs dual-gate MESFETs and Hall devices were fabricated with Si implant into GaAs, and activation of Si dopant following implantation into InP was achieved with capless annealing. Ar laser recrystallization studies were carried out with poly-Si and RF-sputtered GaAs and InP. Following laser crystallization, a grain size of 1 to 2 microns was realized, and experimental Schottky diodes were fabricated on these films.

Wu Bailu, of the Chinese Academy of Sciences Graduate School, and Zhang Aizhen, of the Beijing Semiconductor Devices Institute, discussed their experimental results on the effect of high pressure oxidation on dopant diffusion in Si. They found the P and As diffusion to be retarded, while there was a transition from oxidation enhanced diffusion (OED) to oxidation retarded diffusion (ORD) for B. They attributed these results to injection of Si interstitials and vacancies. Zhang Weixin, of Tianjin University, on the other hand, studied the OED of As in Si and found a direct dependence of As OED on the oxidation rate. This has been attributed to the enhancement of point defect concentration with oxidation rate.

A computer simulation study of impurity diffusion through double layers, such as poly-Si/c-Si, was reported by Tang Yusheng et al. of Shanghai Jiaotong University. They used two sets of difference equations with appropriate boundary conditions for the double layer interface and found good agreement with experimental impurity concentration profiles. Xu Juyan and Wang Limo, of the Wuxi Microelectronics Research Centre, presented their theoretical calculations of average carrier mobility in nonuniform doped layers and applied their average mobility curves to relate the surface impurity concentration and sheet resistance.

Huang Weining and coworkers at Fudan University presented the results of a study of very shallow p-n junction formation using BF_2 implantation followed by rapid thermal annealing (RTA). They were able to achieve much shallower junctions (0.2 micron) and higher surface concentrations (8 x 10^{19} cm^{-3}) relative to B implantation and activation by conventional thermal anneal. The disorder introduced by BF_2 implantation was considerably higher than that with B implant, but the Raman scattering spectrum was found to return to that of virgin Si after the RTA treatment.

A Rutherford backscattering (RBS) study of displacement damage introduced in Si by Ar ion beam etching was reported by Zhou Zuyao et al. of the Shanghai Institute of Metallurgy.

The number of displaced Si atoms was found to saturate beyond the amorphization threshold dose of 5 x 10^{15} cm^{-2}, implying that the damage layer remains constant in thickness but moves inward at a rate equal to the Ar sputtering rate. The thickness of the damage layer was found to vary as the square root of Ar energy, with no dependence on the Si orientation. Tonghe Zhang et al., of Beijing Normal University, discussed their theoretical and transmission electron microscope (TEM) study of oxygen recoil implantation through SiO_2. They found that recoil oxygen introduces dense defects located well below (over 100 nm depending on As implant energy) the surface. These defects are different from those introduced by the As implant itself and require annealing at 1,100 °C for 100 minutes for elimination.

A nondestructive determination of ion implantation damage profile by spectroscopic ellipsometry (SE) was described by He Xingfei and Mo Dang of Zhongshan University, Guangzhou. While the SE technique has been used in recent years to determine the thicknesses of multilayer structures including damage layers, this work represents the first attempt to obtain the damage profile.

SILICON MATERIALS

A study of the properties of thermal donors in Czochralski (CZ) Si crystals was reported by L.Y. Lin et al. of the Institute of Semiconductors, Academia Sinica, Beijing. Using a variety of electrical and optical measurements, they identified three different thermal donor centers and also related their evolution to the presence of interstitial oxygen, substitutional carbon, as well microdefects in the as-grown material.

Zong Xiangfu and colleagues, of the Institute of Material Science, Fudan University, Shanghai, presented the results of an experimental study of oxygen intrinsic gettering. They studied the efficacy of the multistage annealing process using analytical techniques such as TEM, infrared (IR) absorption, and neutron activation analysis and correlated the results with diode leakage and generation lifetime measurements.

Zhou Shiren et al., of the Harbin Institute of Technology, and Wang Shouyu et al., of the Hegans Semiconductor Material Factory, presented their work on a novel magnetic-field-assisted CZ Si growth technique. The purpose of the magnetic field is to control the concentration of oxygen in the CZ crystal and also to improve the radial and longitudinal uniformity of the oxygen concentration. With a magnetic field having both transverse and vertical components, they were able to achieve excellent radial uniformity while reducing the oxygen concentration variation from the seed end to tail by a factor of 3 relative to the conventional CZ technique.

A study of thermal donor creation in neutron transmutation doped (NTD) CZ Si was presented by Meng Xiangti of the Institute of Nuclear Energy Technology, Tsinghua University, Beijing. Two different thermal donors were found to result, depending on the anneal temperature range, and the influence of neutron irradiation on oxygen precipitation and complexing was assessed. Wu Gengmei and colleagues, of the Department of Physics, Nanjing University, described their study of minority carrier lifetime control in Si using 12-MeV electron irradiation. Compared to the conventional Au or Pt diffusion technique, better parameter tradeoffs, lower leakage current, and narrower parameter spreads were

obtained. The use of deeper penetrating high-energy electrons also enables irradiation of packaged devices. Better long-term stability is achieved with the creation of suitable defect centers.

Li Gang et al., of the Semiconductor Material Institute, Zhejiang University, Hangzhou, presented a laser-assisted diffusion technique for forming ohmic contacts to high-resistivity Si. A theoretical study of the electronic structure of hydrogen in Si was presented by Cui Shufan and Mai Zhenhong of the Institute of Physics, Academia Sinica, Beijing. The influence of hydrogen in NTD Si was studied by M.W. Qi et al. of the Shanghai Institute of Metallurgy using IR spectroscopy. Their results suggest that irradiation-induced defects and defect clusters determine a number of IR absorption bands, not necessarily correlated with hydrogen.

An epitaxial growth process for high-purity p-type Si was described by Zhao Yongfa and colleagues from the Electronic Materials Research Institute, Tianjin. Resistivities as high as 500 to 700 ohm-cm were obtained on epi layers grown using a trichlorosilane source. Xia Deqian and Chen Hongyi, of the Nanjing Solid State Devices Research Institute, presented their results on semi-insulating (SI) GaAs grown in a high-pressure liquid encapsulated Czochralski (LEC) reactor they had developed. With a high-temperature hydrogen anneal following crystal growth, resistivities exceeding 30 MΩ-cm and mobilities greater than 3,000 cm^2/V-s were achieved. Their SI GaAs has served as substrate material for subsequent fabrication of GaAs field effect transistors.

THIN FILM TECHNOLOGY

Most of the papers presented by Chinese researchers in this area dealt with various aspects of silicides for use in IC technology. Wang Yongfa and colleagues, of Fudan University, Shanghai, presented their thermodynamic calculations for chemical vapor deposition (CVD) of tungsten silicide. The results project optimal temperature and pressure required for the desired reactions. The same group also presented their computer simulation of film thickness distribution in low pressure CVD processes. This, of course, is a very important practical problem, and they claim close agreement of theory with experimental results presented in the literature. Jiang Xiangliu and coworkers, at the Semiconductor Device Research Institute, Beijing, presented their experimental results on low pressure CVD deposited poly-Si of high conductivity. Both n- and p-type films have been deposited with resistivities below 0.004 ohm-cm.

Tungsten silicide formation at the Si surface by ion beam mixing was investigated by Ding Xunliang et al. of the Institute of Low Energy Nuclear Physics, Beijing Normal University. They implanted 150-keV As to a dose of about 10^{16} cm^{-2} onto Si substrates coated previously with a multilayer of Si and W. They studied the silicide formation process with Rutherford backscattering and x-ray diffraction (XRD) and found that refractory tungsten silicide can be formed at reduced reaction temperature with ion beam mixing. The same group also reported on the formation of molybdenum and niobium silicides with ion beam mixing followed by rapid thermal annealing (RTA). The redistribution of As dopant was found to be minimized due to the use of RTA.

Hong Feng and colleagues, at Fudan University, Shanghai, studied the Ti–Si interaction using XRD. Of obvious interest in the self-aligned silicide (salicide) technology for very large scale integration (VLSI), their results show the dependence of $TiSi_2$ evolution on the reaction conditions and Si substrate orientation. Xu Qiuxia and Ma Junru, of the Institute of Semiconductors, Academia Sinica, Beijing, took an alternative approach to titanium silicide growth: they implanted Ti into poly–Si and found that they could avoid the usual contamination problems associated with the conventional cosputtering process. It is projected that the method will find application for MOS gate electrodes as well as interconnects with the incipient development of broad beam implanters.

AMORPHOUS SILICON

The intense interest in hydrogenated amorphous Si (a–Si:H) and related alloys for terrestrial photovoltaics is well known. However, these materials have generally elicited skepticism in the conventional Si VLSI field due mainly to concerns about the presence of hydrogen, which effuses out at low temperatures. Nevertheless, with the evolution of low–temperature processing for VLSI, the potential of this new class of semiconductor materials in crystalline Si (c–SI) technology cannot be ignored. This fact had apparently been recognized by the organizers of this conference, and the result was a complete session devoted to amorphous silicon.

Z.M. Chen and coworkers, at the Institute of Semiconductors, Academia Sinica, Beijing, reported the characteristics of a–Si:H/a–C:H and a–Si:H/microcrystalline Si:H superlattices grown in their laboratory using the RF glow discharge technique. They studied the optical absorption as a function of superlattice period and observed clear evidence for carrier confinement in one–dimensional potential wells. A theoretical analysis of the internal photoemission transient in a metal/a–Si:H/c–Si structure was presented by Su Zimin et al. of the Department of Physics, Zhongshan University, Guangzhou. It was shown that both the bulk and interfacial trap distributions could be obtained from these transient measurements. The properties of microcrystalline Si:H prepared by glow discharge decomposition of silane were described by Cao Baochong et al. of the Department of Physics, Shandong University, Jinan.

Hsiangna Liu and colleagues, of the Physics Department and Institute of Solid State Physics, Nanjing University, reported on their study of light–induced metastable changes in photoconductivity (Staebler–Wronski effect) in doped and undoped microcrystalline Si:H. They evaluated the doping dependence of the effect and also found that the Si dangling bond density (determined by electron spin resonance) increased with the microcrystal grain size. The latter is indicative of dangling bonds being associated with grain boundaries. A study of thermal annealing on a–Si:H was reported by Zhao Shifu et al. of the Institute of Physics, Academia Sinica, Beijing. They found that hydrogen effusion at a given anneal temperature increases as the deposition temperature is lowered. They also noted changes in optical gap and Urbach edge for an anneal temperature of 350 °C.

Wu Zhongyan and Shen Yuehua, of the Shanghai Institute of Ceramics, presented their work on Ga and In doping of a–Si:H. They found higher photoconductivity with Ga and In than with the conventional B doping, while the absorption edge changed negligibly. Thus, the doping efficiency is seen to be higher with Ga and In.

A theoretical model to explain the high ideality factor and temperature dependence of the current-voltage characteristics of a-Si:H p-i-n diodes was presented by Zhongde Xi and coworkers of Peking University. The model assumes an exponential distribution of both donorlike and acceptorlike gap states as the basis for deriving a Shockley-Read-Hall type recombination rate equation for the amorphous semiconductor. Good agreement with experimental data has been found.

SILICON-ON-INSULATOR (SOI) TECHNOLOGIES

This session brought into focus the various Chinese efforts on this emerging technological front. The lead-off paper, presented by Tsien Peihsin et al., of the Institute of Microelectronics, Tsinghua University, Beijing, outlined their development of a three-dimensional compound MOS (CMOS) ring oscillator using a laser recrystallized poly-Si layer for the p-channel transistor. A propagation delay of 2.7 ns per stage was reported with a channel length of 5 microns. Z.Y. Shen et al., of the Shanghai Institute of Metallurgy, Academia Sinica, on the other hand, described a fully ion-implanted CMOS/SOI process wherein both the p- and n-channel transistors were fabricated on laser recrystallized poly-Si. With a channel length of 6 microns, a nine-stage ring oscillator yielded a propagation delay of 2.8 ns per stage.

A study of buried Si_3N_4 formation in Si with 300-keV nitrogen ion implantation was presented by Chen Hui et al. of the Institute of Microelectronics, Tsinghua University. Cross-sectional TEM delineated the existence of six layers following the implantation step. Capacitance-voltage and spreading resistance measurements were also carried out on the sample after the required 1,200-°C, 2-hour anneal. The microstructure and process model of nitrogen-implanted SOI was described by C. Ren and P.N. Zhao of the Shanghai Institute of Metallurgy, Academia Sinica. Using a variety of analytical tools, they identified two different mechanisms for the formation of Si_3N_4: nitridation by (1) excess nitrogen diffusion and (2) nitrogen diffusion caused by silicon nitride precipitation.

Laser crystallization of a-Si:H on insulators was studied by Bao Ximao and Huang Xinfan of the Department of Physics, Nanjing University. They found four modes of crystallization depending on the laser power, scan speed, and substrate temperature. F. Fang and coworkers, at the Shanghai Institute of Metallurgy, presented their characterization of Si/SiO_2 interface traps in MOS structures fabricated on Ar laser recrystallized poly-Si. Using deep level transient spectroscopy (DLTS), they were able to determine the interface as well as bulk trap densities.

MOSFETs fabricated on SOI Si grown by graphite strip heater lateral seeded recrystallization were described by Ji Fuquan et al. of the Department of Physics, Nanjing University. Grain sizes of several millimeters were obtained, and this resulted in p-channel MOS transistors with performance comparable to that of devices made on single-crystal Si. A surface hole mobility of 190 cm^2/V-s was calculated from the MOS current-voltage characteristics.

SUMMARY

The conference agenda also included a catalog show from semiconductor equipment manufacturers and evening panel discussions. The

organization was very effective in providing opportunities for personal interaction between participants. Following the conference, technical visits to the Institute of Semiconductors, Academia Sinica, and the Microelectronics Institute, Tsinghua University, were arranged for interested participants. These are among the premier semiconductor research institutions in China and provided a glimpse of the accomplishments and goals of Chinese engineers and scientists in this field. While advanced research and development in VLSI requires sophisticated equipment that presently needs to be imported, the Chinese researchers have also taken great pains to develop their own systems.

In summary, the conference provided a lively opportunity to learn about the many impressive Chinese efforts in the semiconductor field and also for mutual exchange of ideas and interests. The emphasis placed by China on semiconductor technology is clearly evident from this very successful conference, and one could certainly sense the excitement in the air.

Dr. S. Ashok is presently an associate professor of engineering sciences at Pennsylvania State University. He received his B.E. degree from P.S.G. College of Technology (University of Madras), Coimbatore, India, a M.Tech. degree from the Indian Institute of Technology, Kanpur, and a Ph.D degree from Rensselaer Polytechnic Institute, Troy, New York, all in electrical engineering. His research interests are in semiconductor devices and materials, thin films, photovoltaics, and interface phenomena. He has authored or coauthored over 75 publications in these areas and has also presented papers at several national and international conferences and symposia. He is the recipient of the Allen Dumont Award at Rensselaer, the Penn State Engineering Society Faculty Research Award, and the Humboldt Fellowship, West Germany.

Appendix

CHINESE-CONTRIBUTED PAPERS

PATTERNING TECHNOLOGY

"Fine Structure of Patterns in Optical Projection Microlithography Systems"
Xu Duanyi, Microengineering Research Centre, Tsinghua University, Beijing

"A Study of Light-Induced Properties of 5-Nitroacenaphthene"
Han Jieping, Ma Junru, Zhong Huili, and Wang Shouwu, Institute of Semiconductors, Academia Sinica, Beijing

"A Language or Thermochemically Approximate Method for Prospect of Mechanism in Plasma Chemical Reactions"
Zhang Chengjou, Nan Tong Transistor Manufacture, Jiangsu; Zou Ziya, Institute of Electronics, Academia Sinica, Beijing

"A Study of Ion Implantation Resisted Etching Technique"
Han Jieping, Wang Peida, Ma Junru, and Wang Shouwu, Institute of Semiconductors, Academia Sinica, Beijing

"A Model of Etching Profile at the Mask Edge"
J.F. Wang, J.L. Yan, G.X. Shen, and Y.S. Xu, Shanghai Institute of Metallurgy, Academia Sinica, Shanghai

SELECTIVE DOPING TECHNIQUES

"A Study of Charge Trapping in Thin Oxide and Simulation of Endurance of Flotox EEPROM Cell"
He Ziaoyin, Zhu Jun, Xiong Daqing, Jin Dongming, Gu Zuyi, Liu Litian, and Li Zhujing, Institute of Microelectronics, Tsinghua University, Beijing

"Dielectric Breakdown Characteristics of Very Thin Thermally Grown Silicon Dioxide Films"
Yang Buyi, Wuxi Microelectronics Research Centre, Jiangsu

"Ion Implantation and Laser Recrystallization of Semiconductors"
Tsou Shihchang, Shanghai Institute of Metallurgy, Academia Sinica, Shanghai

"The Effect of High Pressure Oxidation on Impurities Diffusion in Silicon"
Wu Bailu, The Chinese Academy of Sciences Graduate School, Beijing; Zhang Aizhen, Beijing Semiconductor Devices Institute, Beijing

"Oxidation-Enhanced Diffusion of Arsenic in Silicon"
Zhang Weixin, Department of Electronic Engineering, Tianjin University, Tianjin

"Redistribution of High Concentration Implanted B+ and As+ in Silicon During Thermal Oxidation"
Tang Tingao, Department of Electronic Engineering, Fudan University, Shanghai; Carlos Aranjo, University of Colorado, Colorado

"The Computer Simulation of Impurity Redistribution in Two-Layer Diffusion Bulk"
Tang Yusheng, Department of Applied Physics, Shanghai Jiaotong University, Shanghai; Lai Yongchun, Low Energy Nuclear Physics Institute, Beijing Normal University, Beijing; Huang Chang, Lishan Microelectronics Research Institute, Shaanxi

"Average Mobility of Carriers in Non-Uniform Doped Layers and Its Applications"
Xu Juyan and Wang Limo, Wuxi Microelectronics Research Centre, Jiangsu

"Shallow P+ N Junction Formation by Rapid Thermal Annealing of BF2+ Implantation"
Huang Weining, Jiang Guobao, Zhang Guoquan, Yue Dequan, Zhou Shifang, and Li Bingzong, Department of Electronic Engineering, Fudan University, Shanghai

"Interaction of Boron and Arsenic Double Ion Implanted into Silicon, Carrier Profile and Its Simulation"
Ma Yi and Li Guohui, Institute of Low Energy Nuclear Physics, Beijing Normal University, Beijing; Huang Chang, Lishan Microelectronics Company, Shaanxi

"An Investigation on Si Surface Damage Induced by Low Energy Ion Beam Sputtering"
Zhou Zuyao, Ren Congxin, Chen Guoming, Hu Jiazeng, Yang Jie, and Tsou Shihchang, Ion Beam Laboratory, Shanghai Institute of Metallurgy, Academia Sinica, Shanghai; Zhu Dezhang and Cao Dexin, Shanghai Institute for Nuclear Research, Academia Sinica, Shanghai

"The Influence of Recoil Oxygen as Implanted Through Film of SiO_2 on Residual Defects"
Tonghe Zhang, Shusheng He, and Diantong Lu, Institute of Low Energy Nuclear Physics, Beijing Normal University

"Nondestructive Analysis of Damage Profile in Ion Implanted Si By Spectroscopic Ellipsometry"
He Xingfei and Mo Dang, Department of Physics, Zhongshan University, Guangzhou

"An Empirical Formula for Estimating Range Parameters R_p and ΔR_p of Heavy Ions Implanted into SiO_2, Al_2O_3, and Si_3N_4"
Li Jinhua, Changzhou Semiconductor Factory, Jiangsu; Zhan Yongen, Xia Yueyuan, and Cheng Esheng, Department of Physics, Shandong University, Jinan, Shandong

SILICON MATERIALS

"A Study on the Properties of New Donors in CZ-Si Crystals"
L.Y. Lin, Z.G. Wang, J.J. Gian, W.K. Ge, S.K. Wan, and R.G. Lin, Institute of Semiconductors, Academia Sinica, Beijing

"Gettering Technology in Silicon"
Zong Xiangfu, Institute of Material Science, Fudan University, Shanghai

"Control of Oxygen Concentration in CZ Si Crystal Growth Furnace with Y-Shape Magnetic Field Distribution"
Zhou Shiren, Ji Yanshu, Kong Qingmao, and Gao Yuankai, Harbin Institute of Technology, Harbin

"Two Oxygen Donors in NTD CZ Si"
Meng Xiangti, Institute of Nuclear Energy Technology, Tsinghua University, Beijing

"Ohmic Contacts on High Resistivity Silicon"
Li Gang, Shen Fuchu, Yao Kuihong, and Que Duanlin, Semiconductor Material Institute, Zhejiang University, Hangzhou, Zhejiang

"Lifetime Control in 12-MeV Electron Irradiated Silicon Devices"
Wu Gengmei, Lai Qiji, Jiang Yongxing, Liu Yongyi, and Zhu Yizhang, Department of Physics, Nanjing University, Nanjing

"Electronic Structure and the Properties of Hydrogen in Silicon"
Cui Shufan and Mai Zhenhong, Institute of Physics, Academia Sinica, Beijing

"Investigation of Electronic Excitation Bands in NTD-Si Containing Hydrogen"
M.W. Qi, T.S. Shi, P.X. Cai, G.R. Bai, and L.M. Xie, Shanghai Institute of Metallurgy, Academia Sinica, Shanghai

"A Mathematical Model on the Variation of Solute Concentration in the Melt in the Growing Process of Heavily Sb-Doped Si Crystal"
She Siming and Cheng Jun, Department of Material Science and Engineering, Central South University of Technology, Hunan

"A Negative Evidence of Molecule-Like Cluster Models of As in Si"
Lu Zhiheng, Institute of Low Energy Nuclear Physics, Beijing Normal University, Beijing

"P-Silicon Purity Epitaxial Growth"
Zhao Yongfa, Wang Jinsheng, Sun Xiuyin, and Hua Qingheng, Electronic Materials Research Institute, Tianjin

"Investigation for Making Single Crystal of SI-GaAs"
Xia Deqian, Nanjing Solid State Devices Research Institute, Nanjing

"Monte Carlo Particle Simulation for NDM of GaAs"
Honglin Zhao, Department of Electronic Engineering, Tianjin University, Tianjin

"MBE Growth of GaAs-AlGaAs (AlAs) Quantum Well and Superlattice Structures"
Chen Zonggui, Sun Dianzhau, Liang Jiben, Huang Yunheng, and Kong Meiying, Institute of Semiconductors, Academia Sinica

RAPID THERMAL ANNEALING

"An Infrared Transient Annealing Technique for Ion Implanted MOS Technology"
Hou Dongyan, Ma Tengge, Chen Bixian, and Tsien Peihsin, Institute of Microelectronics, Tsinghua University, Beijing

"The Study of Rapid Thermal Annealing of Si+ Implanted SI-GaAs"
Liang Zhenxian and Luo Jinsheng, Institute of Microelectronics Technology, Xian Jiaotong University, Xian, Shaanxi

"Rapid Annealing Using Large Area Uniform Electron Beam on Ion Implanted Silicon"
Jiang Xiangliu and Chu Hongliang, Beijing Semiconductor Device Research Institute, Beijing; Yu Zhenqi, Du Yuanchen, and Sun Xuanchi, Physics Department, Fudan University, Shanghai

"Rapid Thermal Annealing of Si-Implanted SI-GaAs"
Li Binghui, Yang Yaozhong, and Deng Xiancan, Hebei Semiconductor Research Institute, Hebei

THIN FILM TECHNOLOGY

"Thermodynamical Study on CVD of Tungsten Silicide"
Wang Yongfa, Zhang Shili, Zhou Qing, and Wang Jitao, Department of Material Science, Fudan University, Shangha

"Computer Simulation of Film Thickness Distribution in LPCVD Process"
Wang Jitao, Zhang Shili, and Wang Yongfa, Department of Material Science, Fudan University, Shanghai

"The Preparation of Gaseous Doped LPCVD Polysilicon Film with High Conductivity"
Jiang Xiangliu, He Yunheng, Liu Xiaobo, and Zhang Wenping, Beijing Semiconductor Device Research Institute, Beijing

"Silicon Stripes Deposited by Laser Induced CVD"
Du Yuancheng, Department of Electronic Engineering, Fudan University, Shanghai; U. Kempfer, K. Piglmayer, and D. Bauerle, Angewandte Physik, Johannes-Kepler University, Linz, Austria

"Structural and Electrical Properties of WSi_2 Films Formed by Ion Beam Mixing"
Ding Xunliang, Wang Zhonglie, and Qian Yahong, Institute of Low Energy Nuclear Physics, Beijing Normal University, Beijing

"An X-Ray Diffraction Study on Ti/Si Solid State Interaction"
Hong Feng and Li Bingzong, Electronic Engineering Department, Fudan University, Shanghai

"An Investigation of a Novel Method for Forming Titanium Silicide"
Xu Qiuxia and Ma Junru, Institute of Semiconductors, Academia Sinica, Beijing

"The Formation of Molybdenum and Niobium Silicides with Ion Beam Mixing Followed by RTA"
Wang Zhonglie, Qian Yahong, Ding Xunlian, and Liu Yili, Institute of Low Energy Nuclear Physics, Beijing Normal University, Beijing

"Properties, Structures and Redistribution of Arsenic During Formation of Coevaporated Niobium Silicide"

Zhang Guobing, Yue Tao, and Wang Yangyuan, Microelectronics Research Laboratory, Peking University, Beijing; Wu Mingfang, Xia Zhonhang, and Yao Shude, Department of Technology Physics, Peking University, Beijing

"Oxidation Characteristics of $TaSi_2$/Si Films in Atmosphere and High Pressure Steam"

Wang Yangyuan and Chen Jinhua, Department of Computer Science and Technology, Peking University, Beijing

"The Study of Interfacial Phase Based on XPS–Pd/Si(111) Interface"

Yingxue Li, Xiewen Wang, and Sicheng Wu, Department of Physics, Peking University, Beijing

"The Experimental Research of Tungsten Silicides GaAs Schottky Contacts"

Zhu Zhongde, Department of Computer Science and Technology, Peking University, Beijing; Zachary J. Lemnios, Ford Microelectronics, Inc., Colorado; Michael D. Strathman and Craig G. Hopkins, Charles Evans & Associates, California; James B. Stimmell, National Semiconductor, California; Nathan W. Cheung, Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, California

"Phosphorus Doped LPCVD Polysilicon"

Lin Yuanzhuang and Wen Zhiping, Liaohe Experiment Research Institute, Shenyang

"Mobility in Heavily Boron–Doped Polysilicon Films"

Wei Xiwen, Zhang Zhaowen, and Wang Meitian, Electronics Department, Dalian Institute of Technology

AMORPHOUS SILICON

"uc–Si:H/a–Si:H and a–Si:H/a–C:H Semiconductor Multilayered Structures"

Z.M. Chen, J.N. Wang, X.Y. Mei, G.L. Kong, and L.Y. Lin, Institute of Semiconductors, Academia Sinica, Beijing

"Effect of Interface States on the Transient Characteristic of Internal Photoemission Current in a Metal/a–Si:H/C–Si Structure"

Su Zimin, Lin Zaimin, and Peng Shaoqi, Department of Physics, Zhongshan University, Guangzhou

"Some Properties of Microcrystalline–Amorphous Si:H Film"

Cao Baochong, Chen Youpong, and Ma Ping, Department of Physics, Shandong University, Jinan

"Some New Results of the Light–Induced Changes in a–Si:H"

Qianqing Ye and Ailien Jung, Department of Mathematics and Physics, Beijing Institute of Aeronautics and Astronautics, Beijing; Shuxiang Wu and En Wu, Department of Physics, Peking University, Beijing

"The Staebler-Wronski Effect in Doped and Undoped Microcrystalline Silicon Films"
Hsiangna Liu, Mingde Xu, and Yuling He, Physics Department and the Institute of Solid State Physics, Nanjing University

"Dependence of the IR and Optical Absorption Edge on the Preparation and Annealing Temperatures of a-Si:H"
Zhao Shifu, Qui Changhau, and Han Daxing, Institute of Physics, Academia Sinica, Beijing; Xi Zhonghe, Yang Datong, and Zhang Guanghua, Department of Radio-Electronics, Peking University, Beijing

"Ga and In Doping Effects on a-Si:H"
Wu Zhongyan and Shen Yuehua, Shanghai Institute of Ceramics, Academia Sinica, Shanghai

"Quality Factor and Current Mechanism in a:Si:H Pin Diodes"
Zhongde Xi, Datong Yang, Guanghua Zhang, and Jia Liu, Department of Radio-Electronics, Peking University, Beijing

SUPERCONDUCTOR ELECTRONICS

"High Tc Nb_3Sn Films and Nb_3Sn Based Josephson Tunnel Junctions Using a New Simple Coevaporation Technique"
Meng Xiaofan and Guo Weixin, Department of Physics, Peking University, Beijing; Wu Xiuwen, Department of Computer Science and Technology, Peking University, Beijing

"A Microstrip Coupling Structure of Josephson Junction for 2e/h Precision Determination"
Kao Chieh, Zhang Chaojun, Zhung Guolin, and Qu Jianguo, National Institute of Metrology, Chengdu, Sichuan

"An Analytic Model of the Semiconductor Coupled Superconducting Field Effect Transistor"
Jiang Jianfei, Research Laboratories of VLSI Electronics, Department of Applied Physics, Shanghai Jiaotong University

"The Effect of Remote Resistive Shunting on dc-SQUID"
Peiran Yan, Yuanyi Zhang, Yin Zhang, Genghau Chen, and Caiwen Yuan, Institute of Physics, Academia Sinica, Beijing

"An Important Question in Measuring Noise of the Josephson Junction Mixer"
Liu Dong, Department of Physics, Northwestern University, Xian; Yang Tao, Hefei Research Institute of Cryogenics and Electronics, The Ministry of Electronic Industry, Hefei

"Investigations on Fabrication and Physics Characteristics of Ultrashort Microbridge Devices"
Ping Yimei, Sun Ziging, Wan Fabao, Fan Jiangshui, and Liu Dong, Physics Department, Northwestern University, Xian

ADVANCED DEVICE TECHNOLOGY

"The Current Gain of N+PN Transistors with Dual Region of N+ Polysilicon and N+ Silicon"
Jiang Xiangliu, Semiconductor Device Research Institute, Beijing

"A Metal Gate Terraced-Gate Oxide Self-Aligned Power VDMOSFET"
Zhu Dazhong and Cheng Qixiu, Department of Radio Engineering, Zhejiang University, Zhejiang

"From Polycrystalline Silicon Emitters to 'Two-Dimensional Electronics Gas Emitters' - A Study of the Noncrystalline Heterojunction Emitters for Bipolar Technology"
Zhu Enjun, Joint Research Laboratory of Nanjing Electronic Devices Research Institute and Microelectronics Institute of Peking University

"Best Surface Doping in Drift Region of Offset-Gate Power MOSFET's with Deep Junctions"
Xinbi Chen, Institute of Microelectronics, Chengdu Institute of Radio Engineering, Sichuan

"Study on GaAs-MESFET With Ion-Implanted Active Layer"
Xu Huijian, Han Jihong, Wu Luxun, Mao Hinghuai, and Yu Tufa, Nanjing Electronic Devices Research Institute, Nanjing

"Compatible Low/High Voltage MOS Devices with Bipolar Analog IC and Technology"
Lai Zongsheng and Xu Weijun, Department of Science and Technology, East China Normal University, Shanghai; Lu Zhebao and Liu Yaoming, Shanghai No. 5 Component Factory

"Semiconductor Multiodes"
Wang Limo, Wuxi Microelectronics Research Centre, Jiangsu

"The Properties of Plasma Enhanced CVD SiO_2/InP Interface"
Zheng Youdou, Jiang Ruolian, and Xu Junming, Department of Physics, Nanjing University, Nanjing

"The Preparation of Germanium Nitride Grown by Thermal Reaction for Ge-MIS Structure"
Hua Qingheng, Tianjin Electronic Materials Research Institute, Tianjin; James Rosenberg and Edward S. Yang, Department of Electrical Engineering, Columbia University, New York

MOS AND BIPOLAR TECHNOLOGY

"Punchthrough Suppression and Characteristics Improvement of 1-Micron MOSFETs"
Zhang Li and Li Ruiwei, Institute of Microelectronics, Tsinghua University, Beijing

"Characterization of 1-Micron LDD MOSFET"
L.S. Xie, X.L. Chen, and Y.S. Xu, Shanghai Institute of Metallurgy, Academia Sinica, Shanghai

"2-Micron Silicon-Gate Advanced Technology of CMOS Logic Circuits"
Yuansen Xu, Xinxiang Zhou, Yuanhua Liu, and Kang Xu, Shanghai Institute of Metallurgy, Academia Sinica, Shanghai

"The Technology Studies of Shallow Junction Formed by Thermally Driving Implanted Arsenic into Silicon from Polysilicon"
Tang Yusheng, Research Laboratories of VLSI Electronics, Department of Applied Physics, Shanghai Jiaotong University, Shanghai; Huang Chang, Science and Technique Committee, Shaanxi Lishan Microelectron Company, Shaanxi; Lai Yongchun, Low Energy Nuclear Physics Institute, Beijing Normal University, Beijing

"A New Process for Dual Polysilicon Structure in MOS RAM"
Jian Zheren, Liu Xianming, and Li Jinzhi, Wuxi Microelectronics Research Centre, Jiangsu

"2-Dimensional Analysis of the Potential Barrier Under the Gap Between Two Electrodes in a Double Layer Polycrystal Silicon Structure"
Wang Shouwu, He Naiming, and Xia Yongwei, Institute of Semiconductors, Academia Sinica, Beijing

"High Frequency Ion-Implanted Dual Gate MOSFET"
Y.X. Li and M. Zhang, Shanghai Institute of Metallurgy, Academia Sinica, Shanghai

"Investigation on Pt-Si Schottky Circuits with Arsenic Implanted Polysilicon Emitter"
Bian Jiang, Liu Youbao, Lu Yinghua, and Huang Chang, Lishan Institute of Microelectronics, Shaanxi

"The Simulation of Hot Carrier Effect in Small Geometry MOSFET"
Wei Tongli and Ho Yie, Electronic Engineering Department, Nanjing Institute of Technology, Nanjing

"Investigation of Bipolar Transistor Temperature Dependence"
Li Xuexin, Lin Yayun, Tian Cheunsheng, and Cheng Yaohai, Reliability Physics Laboratory, Beijing Polytechnic University, Beijing

"High-Speed High-Density Bipolar LSI Technology"
M.Q. Chen, F.C. Wu, B.Y. Zhou, J.L. Lu, M.G. Xie, D.Z. He, and Y.S. Xu, Shanghai Institute of Metallurgy, Academia Sinica, Shanghai

"A Study on the Characterization of Semi-Insulating Polycrystalline (SIPOS) - Silicon Heterojunction"
Wang Yunzhen and Pan Yaoling, Department of Electronic Science and Technology, East China Normal University, Shanghai

"A Semi-Global Method for the Parameter Extraction of BJT dc-Model"
Xiangdong Wu, Sichuan Solid-State Circuits Research Institute, Sichuan; Robert W. Dutton, Department of Electrical Engineering, Stanford University, California

CIRCUIT DESIGN

"The Total Quality of Carriers Analysis Method"
C. Huang, M. Du, H. Tien, and F. Wang, Shaanxi Microelectronics Research Institute, Shaanxi

"A News Approach to Structure and Process Design Optimization of Short Channel MOSFET for Digital VLSI Circuits"
Chen Datong and Li Zhijian, Institute of Microelectronics, Tsinghua University, Beijing

"Simulation and Design of Short-Channel Radiation-Hardened LDD CMOS Integrated Circuits"
F. Wang, S. Xiao, M. Du, Q. Lu, Y.B. Li, Q.Q. Song, and C. Huang, Shaanxi Microelectronics Research Institute, Shaanxi

"A New Model for Threshold Voltage of Short Channel Depletion Mode MOSFET"
Ho Yie and Wei Tongli, Electronic Engineering Department, Nanjing Institute of Technology, Nanjing

"Numerical Analysis of the Threshold Voltage of MOSFET's"
Ji Chaoren, Zhou Menglin, and Yang Biao, Shanghai University of Science and Technology, Shanghai

"Theory of the Optimum Design on Ultra Large Scale Memory Systems"
Zhang Guoying, Tianjing Semiconductor Device Factory, Tianjing

"Application of B Spline Function Device Interpolation Model in IC Circuit Simulation Program SPICE"
Yan Zhixin, Department of Physics, Shanghai Science and Technology University, Shanghai; Wang Bijuan and Yao Linsheng, Shanghai Institute of Metallurgy, Academia Sinica, Shanghai

"LSIS-II Automatic Layout Design System"
W.J. Zhuang, K.X. Cheng, J.G. Bo, Z.H. Niu, C.H. Gao, F.L. Yi, CAD Group of 4th Division, Institute of Semiconductors, Academia Sinica, Beijing

"Noise Simulation and Low Noise Design for MOS Operational Amplifier"
Wang Guoyu, Microelectronics Center, Nanjing Institute of Technology, Nanjing; Nan Deheng, Microelectronics Research Institute, Tsinghua University, Beijing

"Simulation and Design of CMOS Ring Oscillators and Substrate Current of LDDBC MOSFET's"
S. Ziao, Q. Lu, and Y.F. Chao, Shaanxi Microelectronics Research Institute, Shaanxi

"High Frequency Effects in MOSFET-C Continuous Time Filters and Their Compensations"

Bingxue Shi, Institute of Microelectronics, Tsinghua University, Beijing; John Khoury, AT&T Bell Laboratories, New Jersey; Yannis Tsividis, Department of Electrical Engineering, Columbia University, New York

"Analog Multiplier-Divider with Lateral Bipolar Transistor in CMOS Technology"

Z. Hong, Institute of Microelectronics, Fudan University, Shanghai; B. Boser, Stanford University, California; H. Melchior, Swiss Federal Institute of Technology, Zurich, Switzerland

"Design of CMOS Input Stage Compatible with TTL Output Level"

Ji Lijiu, Shen Timing, Li Youbin, and Ni Xuewen, Department of Computer Science and Technology, Peking University, Beijing

"Bulk CMOS Latch Up Failure and Its Path Restrain"

Zhao Chuncheng, Lu Zhangsen, Liu Tieping, Go Ping, and Zhen Shufen, Beijing No. 3 Semiconductor Device Factory, Beijing

"A Static and High Sensitive Flip-Flop Sense Amplifier for HMOS-SRAM"

Zhang Zhongxuan, Yang Zhaomin, Zang Mingbao, and Xu Jiashen, Institute of Microelectronics, Tsinghua University, Beijing

"A New Device for the Analog Integrated Circuit - HGET"

Man Lung and Qian Qiao, Department of Electronic Sciences, Nan Kai University, Tian Jin

"The Effect of Feed Forward Capacitor on GaAs MESFET Logic Circuit"

Liang Shan, Ma Zhenchang, Yang Yaozhong, He Jiaqi, and Deng Xiancan, Hebei Semiconductor Research Institute, Hebei

SILICON-ON-INSULATOR TECHNOLOGIES

"Three-Dimensional CMOS IC's Technology and Characteristics"

Tsien Peihsin, Ma Tengge, Shan Jing, Zhou Yinpeng, Chen Bixian, Lin Huiwang, and Zhou Yucheng, Institute of Microelectronics, Tsinghua University, Beijing

"Full Ion Implanted CMOS/SOI Devices"

Z.Y. Shen, C.L. Lin, F. Fang, and S.C. Zon, Shanghai Institute of Metallurgy, Academia Sinica; Z. Xue and G.G. Lin, Shanghai Radio Factory No. 14, Shanghai

"A Study of $Si/Si_3N_4/Si$ Multi-Layer Structure Produced by High-Dose Nitrogen Ion Implantation into Silicon Wafer"

Chen Hui, Wang Rong, Lin Yufeng, Li Weizhong, Zhang Jisheng, and Li Zhijian, Institute of Microelectronics, Tsinghua University, Beijing

"The Microstructure and Process Model of Nitrogen-Implanted SOI"

C. Ren and P.N. Zhao, IC Research Laboratory, Shanghai Institute of Metallurgy, Academia Sinica, Shanghai

"CW Argon Laser Induced Zone-Melting Recrystallization on Thin Silicon on Oxide"
Xu Qiuxia, Institute of Semiconductors, Academia Sinica, Beijing

"Laser Crystallization of a-Si:H on Insulator"
Bao Ximao and Huang Xinfan, Department of Physics, Nanjing University, Nanjing

"Deep Level Transient Spectroscopy in CW Ar+ Laser Recrystallized Polysilicon"
F. Fang, Z. Wu, C.L. Lin, Z.Y. Sheng, and S.C. Tsou, Shanghai Institute of Metallurgy, Academia Sinica, Shanghai

"SOI Technology for 3-Dimension Devices and Integrated Circuits"
Wang Yangyuan and Wang Erwen, Microelectronics Research Laboratory, Peking University, Beijing

"MOSFET's Fabricated in Zone Melting Recrystallized Silicon Films by Means of Graphite Strip Heater"
Ji Fuquan, Li Kemei, Zhou Jianjin, and Ji Ningliang, Department of Physics, Nanjing University, Nanjing

"Thin Bulk Effects in SOI Structure"
Wang Shouwu, Xia Yongwei, Kong Lingkun, Zhang Dongxuan, Institute of Semiconductors, Academia Sinica, Beijing

YIELD/RELIABILITY

"Failure Mechanism Analysis of Semiconductor Devices with Deep Level Transient Spectroscopy"
Zhang Ankang, Electronic Engineering Department, Nanjing Institute of Technology

"LSI Process Characterization and Failure Mechanism Analysis by SEM"
Zhang Ming, Liu Yongkuan, Xiao Huaming, and Liu Xueru, Wuxi Microelectronics Research Centre, Jiangsu

"Measuring Temperature Distribution on Semiconductor Chip by Using Infrared Microimager"
Gao Guangbo, Wu Wuchen, Gui Xiang, Zhu Jingjing, and Miao Miao, Reliability Physics Laboratory, Department of Radio-Electronics, Beijing Polytechnic University, Beijing

"Measurement and Analysis of the Time Dependent Dielectric Breakdown (TDDB)"
Fan Huanzhang and Sun Wei, Department of Electronic Science and Technology, East China Normal University, Shanghai

"Influence of Gamma Irradiation on Mobile Ions in MOS Structure"
Lu Shiji and Zhao Jie, Department of Electronic Engineering, Nanjing Institute of Technology, Nanjing

"Action of a-SI:H/SiNx Multilayered Passivation Film on Improving Low Frequency Noise in ICs"
Zhu Zhaozong, Peng Jun, and Zhang Heming, 502 Section, Northwest Telecommunication Engineering Institute, Xian

PROCESS CHARACTERIZATION

"A Simple Method to Evaluate Low Frequency ac Small Signal Parameters of Semiconductor Devices"
Zhiping Yu, Institute of Microelectronics, Tsinghua University, Beijing; Robert W. Dutton, Integrated Circuits Laboratory, Stanford University, California; Massimo Vanzi, Central R&D, SGS Microelectronics, Agrate (MI), Italy

"MOS Charge Transient Spectroscopy (MQTS) Used for Reliable Si/SiO_2 Interface State Density DIT(E) Measurement"
Zheng Xinyu and Li Zhijian, Institute of Microelectronics, Tsinghua University, Beijing

"MOS Constant Current Harmonic Technique for Determining the Densities and Capture Cross Section of Surface States at Si/SiO_2 Interface"
Tan Changhua and Xu Mingzhen, Department of Computer Science and Technology, Peking University, Beijing

"A Cost-Effective Method for Testing Microcomputer Family Devices"
Xu Zhongyou, Liaohe Experiment Research Institute, Shenyang

MATERIALS CHARACTERIZATION

"Micro-Computer Programmed DLTS Measurement"
Zheng Xiangqin, Physics Department of Nanjing University

"A Metrology Standard for the Monocrystal Silicon Resistivity"
Li Dahan, National Institute of Metrology, Beijing

"A Multifunctional Computerized Semiconductor C-V Measurement System and Its Applications"
Chen Guangsui and Chen Minqi, Research Division of Microelectronics Technology, Xian Jiaotong University, Xian

"Investigation of N-Doped FZ Si Crystals"
J.W. Liang, L.S. Deng, H.F. Luan, and H.J. Zheng, Institute of Semiconductors, Academia Sinica, Beijing

"Shift of Frequencies of Si-H IR Absorption Spectra in Solid State Silicon"
Cui Shufan, Ma Zhenhong, and Chu Xi, Institute of Physics, Academia Sinica, Beijing

"Carrier Transport in Semiconductor Device Physics"
Liu Gu, Department of Physics, Zhejiang University, Zhejiang

"Establishing Calibration Curves for Determination of Oxygen and Carbon in Silicon for Infrared Absorption Method"

Zhang Jiading, Hua Zhifen, and Bao Jingrong, Shanghai Institute of Nuclear Research, Academia Sinica, Shanghai; Ma Lanfen, Shanghai Institute of Testing Technology; Xuan Zenguo and Li Hui, E-Me Institute of Semiconductor Materials, Sichuan

"A Study on Interface of Hgl-xCdxTe With Passivation Film"

Yifang Chen, Jiaxiong Fang, and Dinyuan Tang, Shanghai Institute of Technical Physics, Academia Sinica, Shanghai

FAB OPERATIONS

"IC High Reliable Hermetically Ceramic Packaging"

Liang Changrui, Yang Cangqiao, Zhang Jianzhong, Jia Lianfeng, Li Maolong, Pan Liyu, and Shang Yuqing, Beijing Dong Guang Electron Device Factory, Beijing

"A Broadband Equivalent Circuit Model of Microstrip Package"

He Jiaqi and Xue Yongjian, Hebei Semiconductor Research Institute, Hebei

"Simultaneous Determination of Trace Metallic and Non-Metallic Impurities in Ultra-Pure Water by ICP Atomic Emission Spectrometry"

Huang Wenyu and Yin Yujiang, Nanjing Electronic Devices Research Institute, Nanjing

PROPELLER-HULL INTERACTION RESEARCH IN JAPAN

Fred Stern

Changes in the industrial structure of Japan have influenced Japanese ship hydrodynamics research and provided an impetus for interest in propeller-hull interaction research. At Osaka University, towing-tank experiments are being conducted to provide detailed measurements for validating computational methods and explicating the flow physics for a propeller-driven ship model. At the University of Osaka Prefecture, circulating-water-channel experiments are being conducted to obtain mean-velocity and turbulence measurements. At Kyushu University, methods for calculating propulsive performance are being developed and free-surface effects and propeller-rudder interaction are being studied. Mitsubishi Heavy Industries is focusing its research on the development of procedures for predicting effective wake distributions.

INTRODUCTION

Research in propeller-hull interaction has been increasing in shipbuilding countries because of the more stringent modern ship performance criteria. It is believed that advancements in efficiency and noise level reduction of ships most likely will come through more careful propeller-hull design. In 1985, the Office of Naval Research, Fluid Dynamics Program began an Accelerated Research Initiative Program in Propeller-Hull Interaction. The University of Iowa is engaged in computational and experimental research as part of this program. A component of the University of Iowa experimental research involves a collaborative project with Osaka University and the University of Osaka Prefecture. On 1-15 November 1986, the author visited Japan to discuss the progress of the collaborative research project and to visit other leading experts at Japanese universities and ship research laboratories (Kyushu University, Mitsubishi Heavy Industries, Hiroshima University, Tokyo University) to view the current status of propeller-hull interaction and related ship hydrodynamics research in Japan. A considerable amount of ship hydrodynamics research is being done at these institutions and others in Japan. However, this article is concerned solely with a summary of propeller-hull interaction research at some of the institutions visited.

Changes in the industrial structure of Japan have influenced Japanese ship hydrodynamics research as a whole and provided an impetus for interest in propeller-hull interaction research. As described by Chiba (1985), heavy industries (jukochodai), such as the shipbuilding industry, are giving way to high-tech industries (keihakutansho), such as the semiconductor industry. These changes, which include the channeling of both human resources (the majority of 1985 university graduates with degrees in science and engineering were employed in high-tech industries) and capital resources ($4 billion invested in the semiconductor industry in 1985, which is larger than the sum invested in iron or other heavy industries) in this direction, are being initiated by the private sector, with the government sector following suit. As a result, and also due to strong competition from other countries, notably Korea, the more traditional heavy industries are working very hard to improve their competitive positions in

world markets. These changes have also affected the departments of naval architecture at Japanese universities. Many of these departments are expanding their programs into nontraditional areas to make their graduates more attractive to a wider variety of industries.

PROPELLER-HULL INTERACTION

For practical reasons, marine propellers are located at the stern of a ship; consequently, they operate in the thick stern boundary layer and near wake. The flow field around the propeller-hull combination is unsteady, three dimensional, and turbulent. It is also interactive, insofar as the propeller-induced flow is dependent on the hull flow, which is itself altered by the presence of the propeller. Historically, methods for the analysis of the propeller-induced flow and those for the hull boundary layer and wake have been developed separately with relatively little attention given to the interaction.

Most work on propeller-hull interaction has focused separately on either thrust deduction (propeller influence on hull resistance) or effective wake (propeller influence on hull boundary layer and wake) and has neglected free surface effects. Thrust deduction is calculated as a completely inviscid phenomenon using inviscid-flow methods to represent both the hull and propeller. Effective wake is calculated under the assumptions that the interaction is inviscid in nature and that the hull boundary layer and wake are thin. Prior to the present computational work at the University of Iowa (e.g., Stern et al., 1986a and 1986b), few rigorous investigations had been attempted, and these were restricted to axisymmetric bodies.

At present, detailed experimental information on propeller-hull interaction is quite limited. The most extensive sets of measurements (circumferentially and phase-averaged mean-velocity profiles) are for simple propeller-hull configurations. Circumferentially averaged mean-velocity profiles upstream of the propeller and body surface pressure and shear-stress distributions are available for some more practical axisymmetric geometries. Limited information is available for the entire flow field of three-dimensional bodies, including turbulence quantities and the propeller slipstream velocity field.

OSAKA UNIVERSITY

Professor I. Tanaka and Dr. Y. Toda, Osaka University, are performing towing-tank experiments using two 4m Series 60 C_B = 0.6 models. The purpose of the experiments is to provide detailed measurements that can be used in validating computational methods and explicating the flow physics of a ship model with and without the propeller in operation. A wooden model is used to obtain steady mean-velocity and pressure profiles with a set of five-hole pitot tubes for simultaneous port and starboard measurements at numerous stations both upstream and downstream of the propeller. The traverse is motorized such that, during a run, a total of eight measurements can be made corresponding to four lateral positions on both the port and starboard sides. The surface pressure distribution is obtained by using a fiber-reinforced-plexiglass model with pressure taps. Figures 1 through 3 show experimental results for the mean-velocity contours at $x/L = 0.975$ and the cross-plane mean-velocity vectors at $x/L = 0.975$ (just upstream of the propeller) and $x/L = 1$ (just downstream of the propeller), respectively, for both the with and without-propeller conditions. The flow boundaries and notation are shown in Figure 4. The flow field

characteristics for the without-propeller condition show the usual pattern associated with a hull form. For the with-propeller condition, the flow within the propeller disk is dominated by the propeller-induced velocity field. There is a general turning of the flow in the clockwise direction due to the action of the propeller, and the flow is asymmetric with respect to the ship centerplane.

Methods for predicting effective wake for three-dimensional bodies are also under development. In earlier work (Toda et al., 1984), three-dimensional boundary layer calculations were made using an integral method in which the propeller-induced velocity is added to the velocity prescribed at the outer edge of the boundary layer. Although the predictions are qualitatively correct, the detailed flow structure is not, due to the lack of variation in propeller-induced velocities across the boundary layer and wake. More recently (Toda et al., 1986), a new approach has been taken that allows for this variation. The new method is basically a clever extension for three-dimensional bodies of the effective wake prediction method for axisymmetric bodies developed at the David Taylor Naval Ship Research and Development Center (DTNSRDC) by T. Huang and associates (1976). Referring to Figure 4 for notation, it is assumed that Huang's method can be applied two dimensionally in x-y planes (i.e., for $z = \text{constant}$) to obtain the lateral propeller-induced flow contraction. The vertical contraction is calculated from potential flow methods with and without the propeller. As shown in Figure 5, the results are quite good even for a rather full form ship ($C_B = 0.837$), a somewhat surprising outcome considering the numerous assumptions.

UNIVERSITY OF OSAKA PREFECTURE

At the University of Osaka Prefecture, Professor Y. Himeno and Dr. T. Okuno are conducting their research in a circulating-water-channel using a 1.8m Series 60 $C_B = 0.6$ model. The purpose of the experiments is to obtain mean-velocity and turbulence measurements for both the with- and without-propeller conditions. The measurements will be made using a two-component wedge-shaped V probe. The model geometry and experimental conditions are similar to those used at Osaka University, although the Reynolds and Froude numbers are slightly different. Also, some differences are to be expected between the towing-tank results and the circulating-water-channel results due to the high freestream turbulence levels and surging phenomena associated with the latter. Although no data are yet available for the with-propeller condition, some previous results obtained with a slant-wedge hot-film probe for a Series 60 $C_B = 0.6$ model without a sterntube (Takeda and Himeno, 1984), which are shown in Figure 6, provide an indication of the differences to be expected. The results shown in Figure 6 are for $x/L = 0.975$ and should be compared with the towing-tank results shown for the same x/L value in Figures 1 and 2. Qualitatively, both the results for the velocity contours and the cross-plane velocity vectors are quite similar, although some differences are seen in the velocity contours near the free surface. The turbulence structure indicated in Figure 6 is similar to wind-tunnel data for similar hull forms. Although some differences may be found between the towing-tank and circulating-water-channel results, overall the results are very satisfactory, creating the expectation that the turbulence measurements for the with- and without-propeller conditions likewise will be extremely valuable.

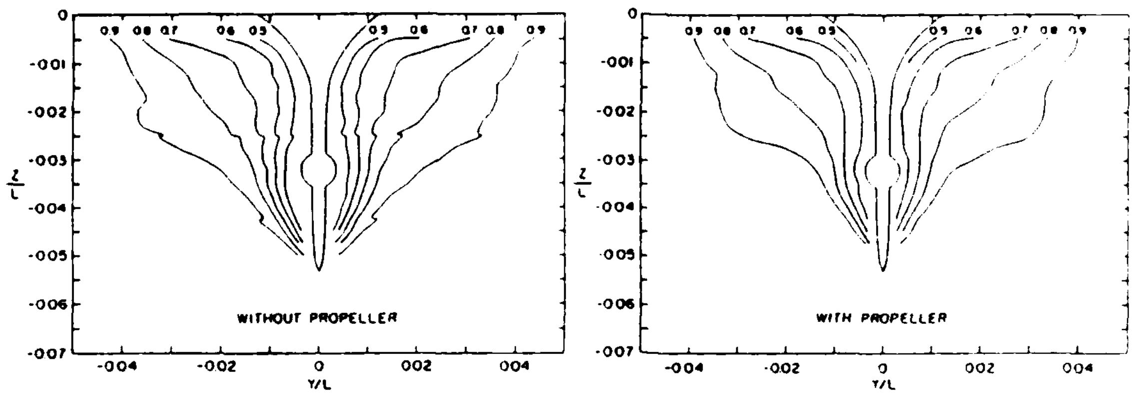


Figure 1. Mean-velocity contours: x/L = 0.975 (Osaka University).

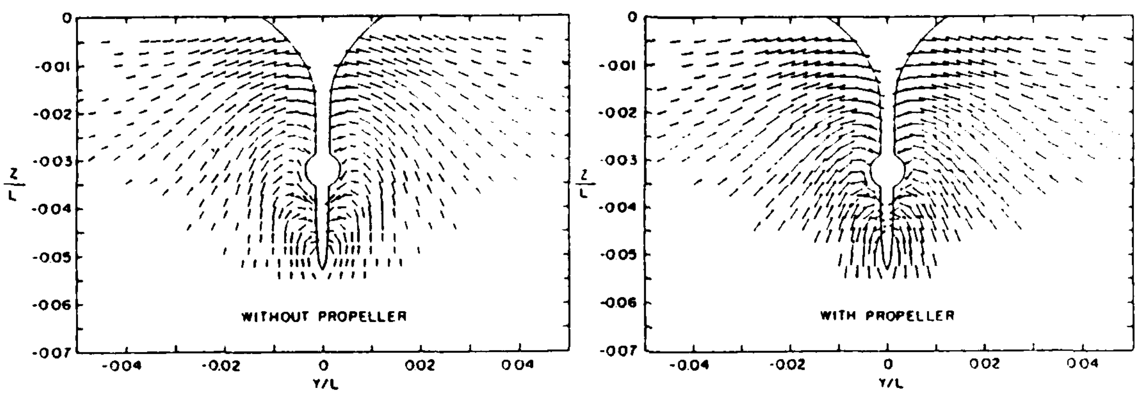


Figure 2. Cross-plane mean-velocity vectors: x/L = 0.975 (Osaka University).

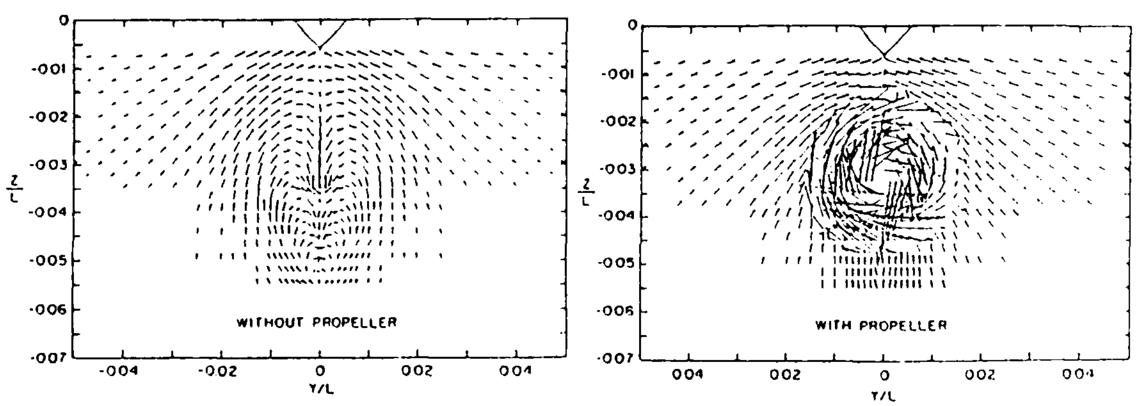


Figure 3. Cross-plane mean-velocity vectors: x/L = 1 (Osaka University).

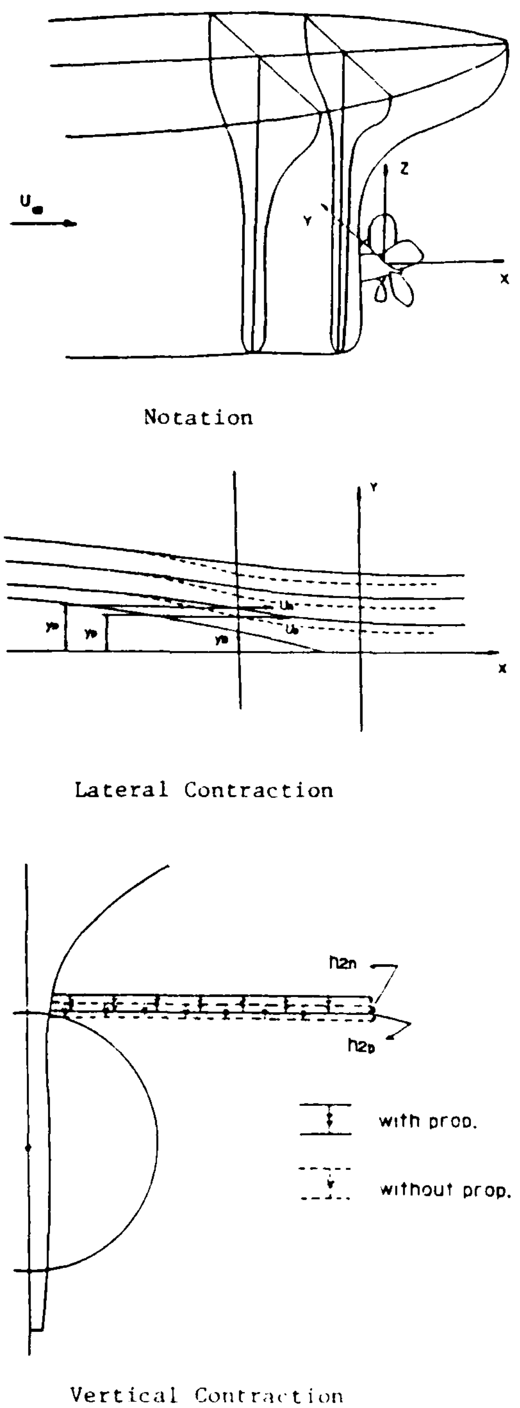


Figure 4. Effective wake prediction method of Toda et al. (1986).

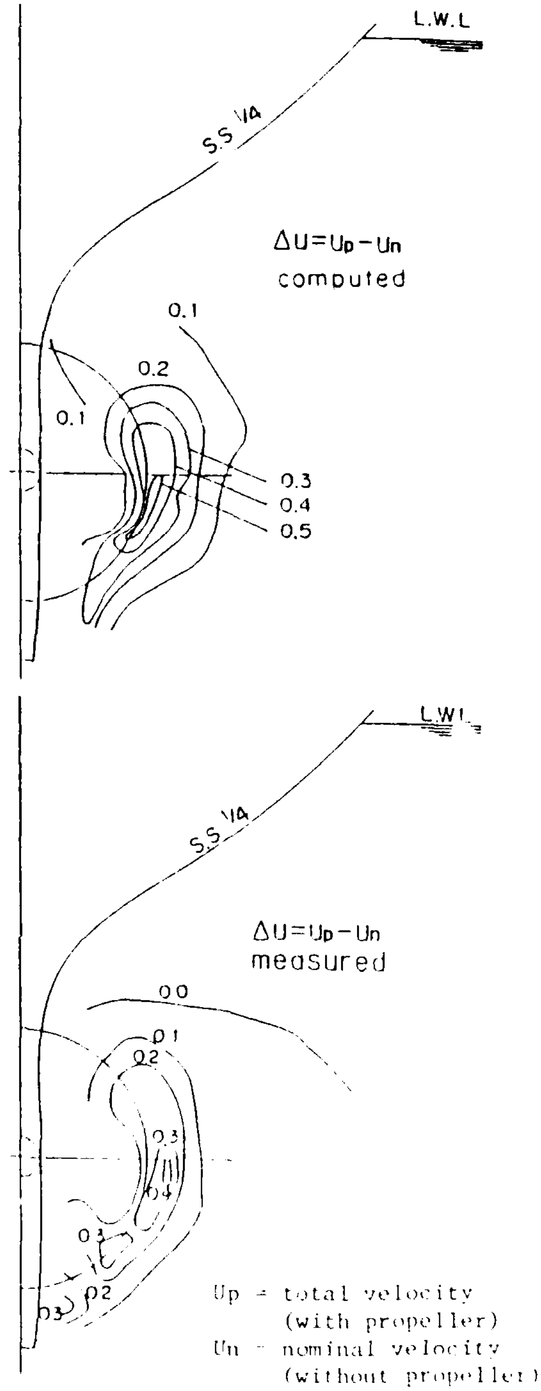


Figure 5. The difference in magnitude between the total and nominal velocities (Toda et al., 1986).

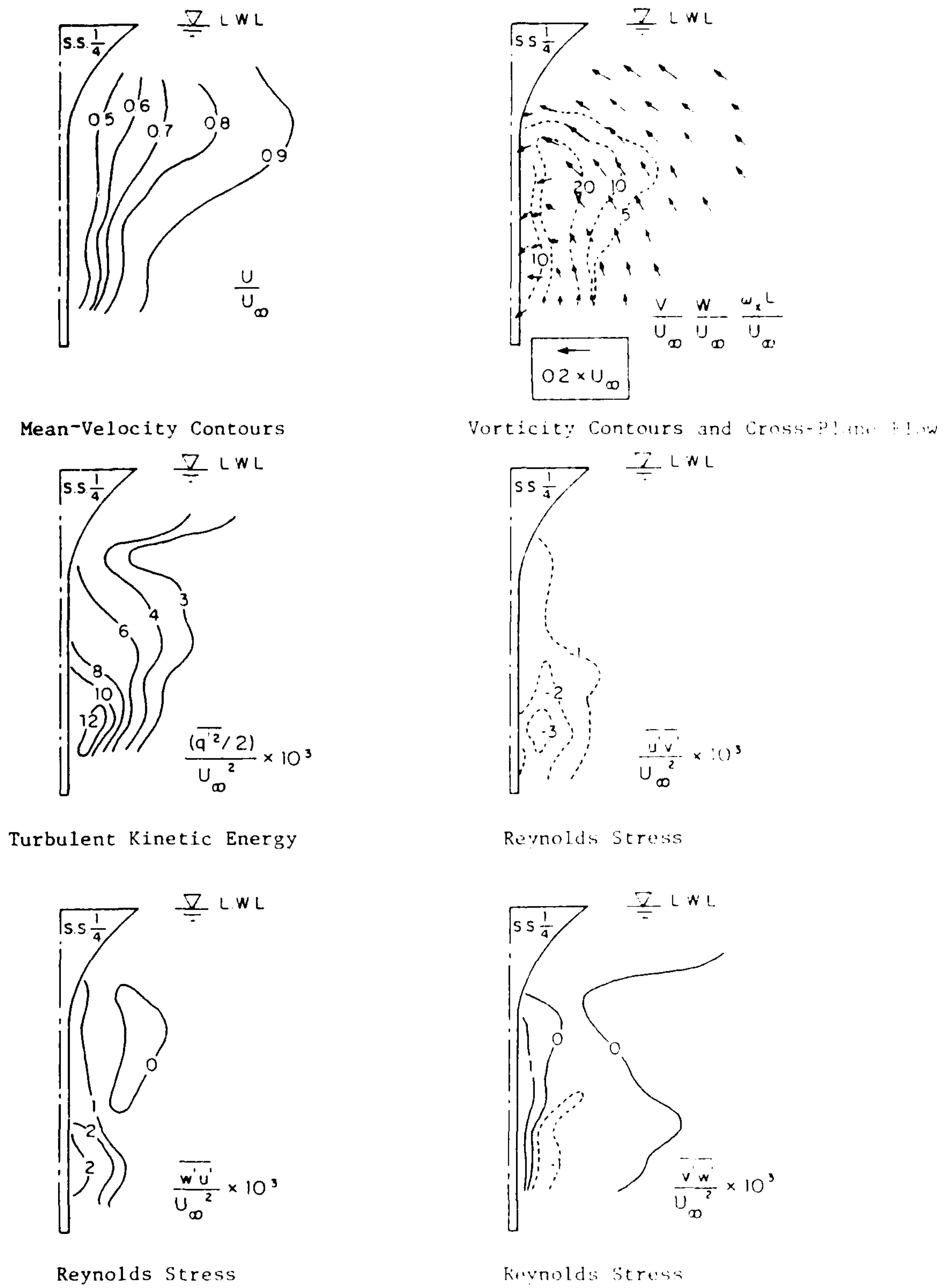


Figure 6. Slant-wedge hot-film probe measurements: x/L = 0.975 (Takeda and Himeno, 1984).

KYUSHU UNIVERSITY

Professors R. Yamazaki and K. Nakatake, and their students, have been very active in the field of propeller-hull interaction for over 20 years. Their interest has focused on the development of methods for calculating propulsive performance (i.e., powering requirements). Their work is comprehensive, that is, their formulation includes such effects as the thick boundary layer and wake near the stern, free-surface waves, the rudder, and hull motions. The general approach, as described by Yamazaki (1980), is a zonal approach, in which various viscous- and inviscid-flow methods are combined interactively to calculate the combined propeller-hull-rudder flow field (Yamazaki, 1985). However, in implementing this approach, numerous approximations have been made, especially with regard to the prediction of the viscous flow, and the focus has been placed on the propulsive coefficients as opposed to the details of the flow field. For example, Nakatake (1981) has circumvented the viscous and wave calculations entirely by using experimental data. Some experimentally observed trends were reproduced.

Studies concerning free-surface effects were reported by Yamazaki and Nakatake (1984), and more recently Nakatake et al. (1986). In their theoretical model, the hull is represented using thin-ship theory, the propeller is represented using Yamazaki's (1977) infinitely bladed propeller theory, and the rudder is represented using thin-wing theory. Viscous effects are neglected. Again, the emphasis is on propulsive coefficients. Typical results are shown in Figure 7 and indicate the following: the thrust deduction, wake fraction, and rudder resistance vary with Froude number; the presence of the rudder increases the effective wake fraction; and the humps and hollows of the rudder resistance correspond to those of the hull resistance.

Studies concerning propeller-rudder interaction were reported by Nakatake et al. (1982) and Yamazaki et al. (1985). In these cases, the propeller was represented using Yamazaki's method (1977), and the rudder was represented using thick-wing theory, including boundary-layer calculations for the frictional resistance. The influence of the propeller pitch, rudder thickness, and axial distance between the rudder and propeller has been studied experimentally and computationally for a simple propeller-rudder geometry in uniform flow. Typical results, which indicate good correlation of theory and experiment, are shown in Figure 8 and indicate the following: the propeller slipstream is disrupted in a complex manner due to the presence of the rudder; for increasing rudder thickness, the thrust and torque slightly increase and the rudder frictional resistance increases substantially; for increasing axial distance between the propeller and rudder, the thrust, torque, and rudder frictional resistance all decrease; and the thrust and torque are increased in the presence of the rudder.

Lastly, Yamazaki et al. (1978) and Yamazaki (1986) have also investigated the influence of ship motions on propulsive performance.

MITSUBISHI HEAVY INDUSTRIES

A large emphasis is being placed on propeller-hull interaction research at Mitsubishi Heavy Industries, Nagasaki Experimental Tank, by Drs. E. Baba, T. Nagamatsu, and their associates. This research is focused on the development of procedures for predicting effective wake distributions. Nagamatsu (1985) has taken a different approach from that described previously by Toda et al. (1986) for including the effects of the variation of the propeller-induced velocity across

the boundary layer. Nagamatsu derives boundary-layer equations for the effective wake by separating the total velocity field into effective and propeller-induced components. He assumes that the effective wake is governed by thin boundary layer order-of-magnitude estimates and that the propeller-induced velocity field is inviscid. The effective-wake boundary-layer equations are solved using a small-cross-flow integral method. The propeller-induced velocities are calculated using Yamazaki's (1977) propeller theory. The resulting equations can be solved for a specified propeller-induced velocity field. Since, in general, this depends on the effective velocity field, the complete solution is obtained iteratively. Figure 9 shows a comparison of the computed results with experimental data for a simple vertical flat-plate body with a propeller operating in the near wake from a downstream propeller boat. Computational results are shown both including the effects of the variation of the propeller-induced velocity across the boundary layer and without including such effects. Also shown are experimental results for the with- and without-propeller conditions just upstream of the propeller for the mean-velocity distribution, cross-plane velocity vectors, pressure distribution, and total pressure distribution. It is seen that inclusion of the variation in propeller-induced velocity across the boundary layer leads to a large improvement in the results. The results shown are for upstream of the propeller. The computational approach (i.e., the use of an integral method) may be difficult to extend into the propeller slipstream.

More recently, Sato and Nagamatsu (1986) have applied these procedures to a more practical ship form, i.e., the Wigley hull. Figure 10 shows some representative results. The agreement with the experimental data is not as good as for the flat plate. This is no doubt due to the use of thin boundary layer order-of-magnitude estimates for the effective flow field. Also, some inaccuracies may result from the cross-flow velocity profile assumption used in the integral method. The results do provide qualitative information concerning the characteristics of the effective wake distribution.

ACKNOWLEDGMENT

I would like to acknowledge and thank my very generous and gracious hosts, Professor I. Tanaka, Professor Y. Himeno, Professor K. Nakatake, Dr. E. Baba, Professor K. Mori, and Professor H. Miyata, who made my trip both enjoyable and immeasurably beneficial to me.

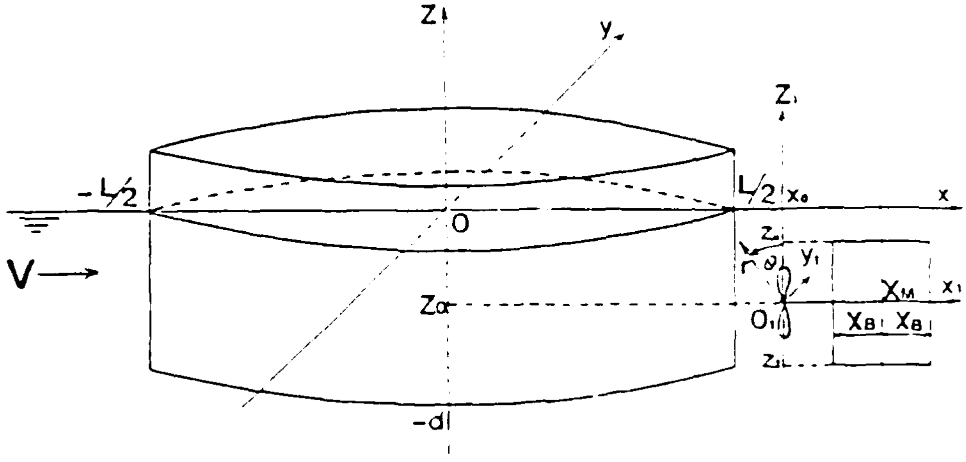
REFERENCES

Chiba, G. 1985. The trends in science and technology and problems of internationalization in Japan. *Scientific Bulletin* 10(4): 101-106.

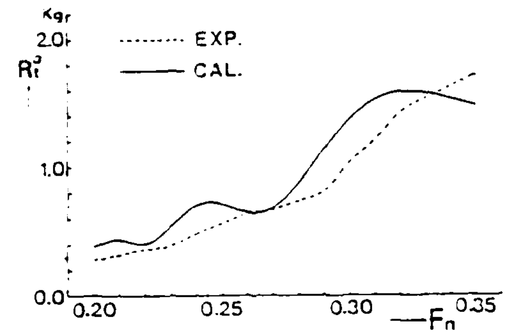
Huang, T.T., W.T. Wang, W. Santelli, and N.C. Groves. 1976. *Propeller stern/boundary-layer interaction of axisymmetric bodies: Theory and experiment*. David Taylor Naval Ship Research and Development Center, Report 76-0113. Bethesda, Md.

Nagamatsu, T. 1985. Effect of propeller on the boundary layer and wake for simple three-dimensional forms. In *Proceedings of the Osaka International Colloquium on Ship Viscous Flow*, 450-467.

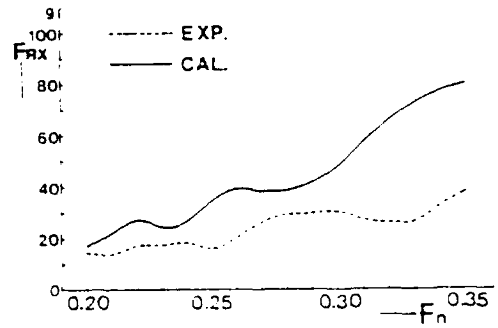
Nakatake, K. 1981. A practical method to calculate propulsive performance of ships. *Memoirs of the Faculty of Engineering* 41(1). Kyushu University.



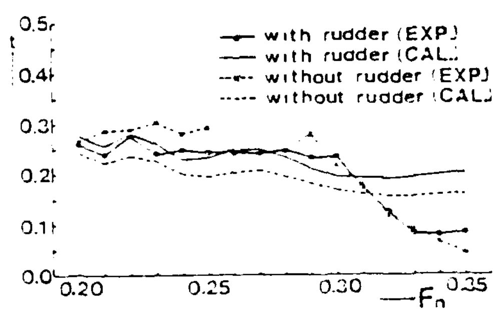
Experimental Model



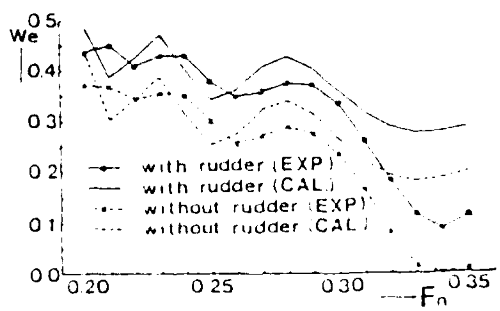
Comparison of hull-resistance



Comparison of rudder resistance in self-propelled condition

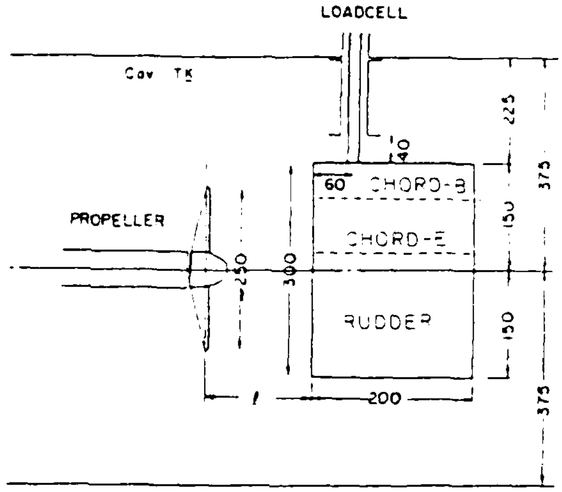


Comparison of thurst deduction fraction

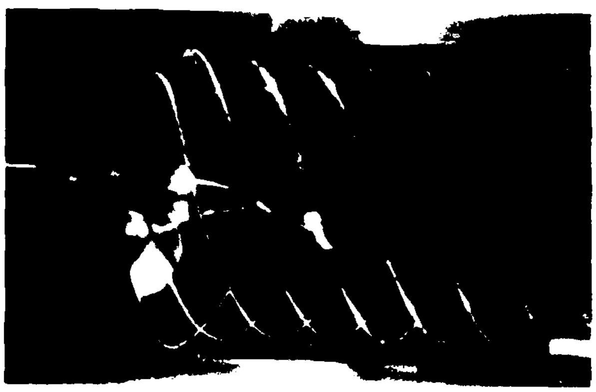


Comparison of effective wake fraction

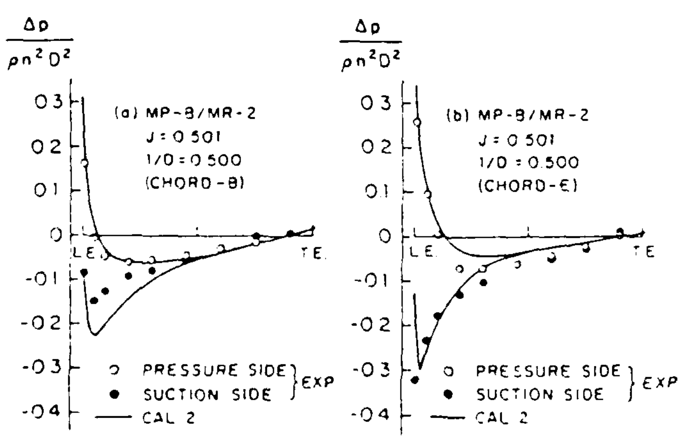
Figure 7. Free-surface effects on propeller-hull interaction (Nakatake et al., 1986).



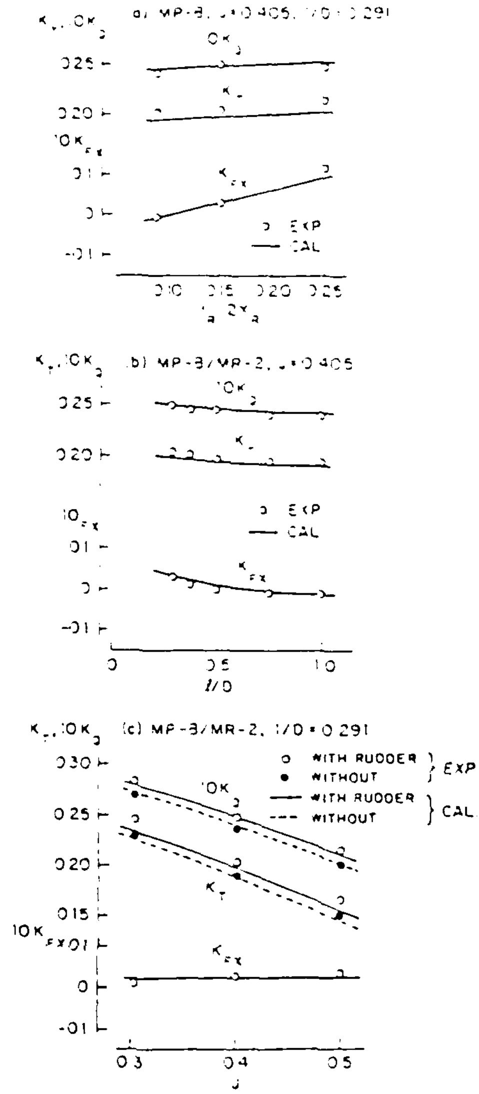
Experimental Configuration



Propeller Slipstream

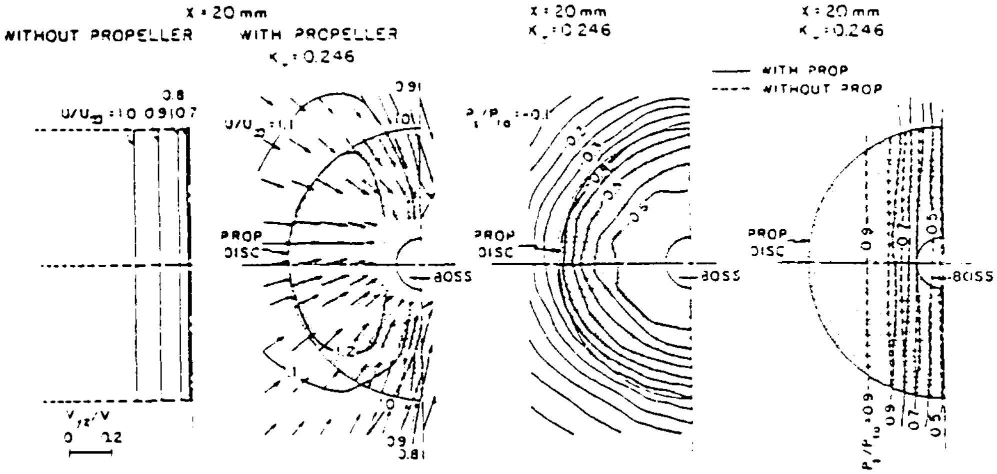


Rudder Pressure Distribution



Influence of Rudder Thickness, Axial Distance, and Advance Ratio

Figure 8. Propeller-rudder interaction (Yamazaki et al., 1985).



Measured velocity distribution in the near wake of flat plate

Pressure distribution in wake of flat plate

Total pressure distribution in wake of flat plate

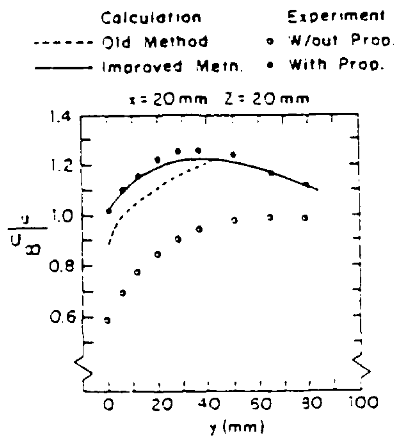
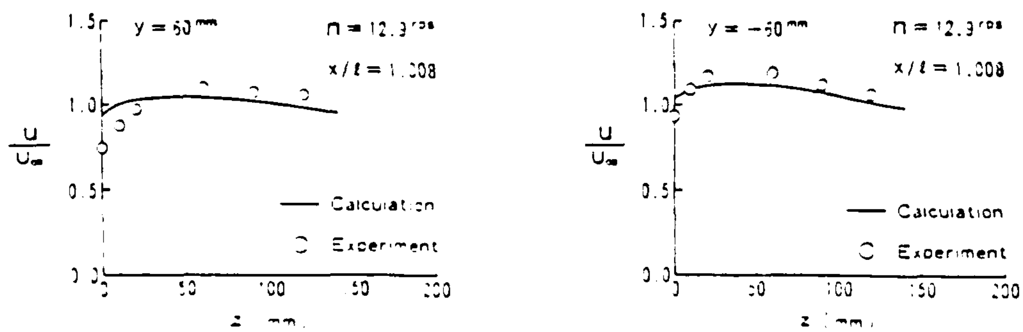


Figure 9. Effective wake prediction method of Nagamatsu (1985).



Comparison of velocity distributions in the wake with propeller

Figure 10. Extensions for simple hull forms: Wigley hull (Sato and Nagamatsu, 1986).

Nakatake, K., K. Oda, K. Kataoka, H. Nishimoto, and J. Ando. 1986. Free surface effect on the propulsive performance of a ship (First report). In *Transactions of the West-Japan Society of Naval Architects*, no. 72: 129–139 (in Japanese).

Nakatake, K., K. Ueda, K. Oda, and R. Yamazaki. 1982. On hydrodynamical force acting on rudder. In *Transactions of the West-Japan Society of Naval Architects*, no. 63 (in Japanese).

Sato, T., and T. Nagamatsu. 1986. Calculation of effective wake distribution of a simple hull form. *Journal of the Society of Naval Architects of Japan* 160: 28–39.

Stern, F., H.T. Kim, V.C. Patel, and H.C. Chen. 1986a. Viscous-flow computations of propeller-hull interaction. In *Proceedings of the 16th Office of Naval Research Symposium on Naval Hydrodynamics.*

Stern, F., H.T. Kim, V.C. Patel, and H.C. Chen. 1986b. *Computation of viscous flow around propeller-shaft configurations.* Iowa Institute of Hydraulic Research, University of Iowa, Report No. 305. Iowa City, Iowa.

Takeda, T., and Y. Himeno. 1984. Turbulence measurement in ship-model flow by means of slanted-wedge hot-film velocimeter. In *Transactions of the West-Japan Society of Naval Architects*, no. 193: 103–113 (in Japanese).

Toda, Y., I. Tanaka, H. Sugioka, and H. Mori. 1984. Distortion of three dimensional boundary layer due to propeller suction. *Journal of the Kansai Society of Naval Architects*, no. 192.

Toda, Y., Y. Kasahara, and I. Tanaka. 1986. Estimation of effective wake distribution of full form ships. In *Proceedings of the Autumn Meeting of the Society of Naval Architects of Japan* (in Japanese).

Yamazaki, R. 1977. On the propulsion theory of ships on still water – Improved theoretical method. *Memoirs of the Faculty of Engineering* 37(1). Kyushu University.

Yamazaki, R. 1980. A new direction in propulsion theory of ships on still water. *Memoirs of the Faculty of Engineering* 40(1). Kyushu University.

Yamazaki, R. 1985. On the propulsion theory of ships on still water – Advanced theoretical method. *Memoirs of the Faculty of Engineering* 45(4). Kyushu University.

Yamazaki R. 1986. On the propulsion theory of a ship in regular waves. In *Transactions of the West-Japan Society of Naval Architects*, no. 72 (in Japanese).

Yamazaki, R., and K. Nakatake. 1984. Free-surface effect on the hull-propeller interaction. In *Proceedings of the 15th Office of Naval Research Symposium on Naval Hydrodynamics.*

Yamazaki, R., K. Nakatake, and F. Moriyama. 1985. On the mutual interaction between the screw propeller and the rudder. *Memoirs of the Faculty of Engineering* 45(1): 80–109. Kyushu University.

Yamazaki, R., K. Nakatake, S. Kino, and K. Koguchi. 1978. On the propulsive performance of a ship in regular head waves. *Journal of the Society of Naval Architects* 143.

Frederick Stern received his Ph.D. in naval architecture and marine engineering from the University of Michigan in 1980. Subsequently, he worked as a research naval architect at Science Applications, Inc., Annapolis, MD, until September 1983, whereupon he assumed his present position as Assistant Professor of Mechanical Engineering and Research Engineer at the Iowa Institute of Hydraulic Research, the University of Iowa. His research interests are in ship hydrodynamics, including viscous flow, propellers and cavitation, potential flow, drag prediction, and ship and platform dynamics. Professor Stern is a member of SNAME and ASEE.

THE THIRD U.S.–JAPAN SEMINAR ON DIELECTRIC AND PIEZOELECTRIC CERAMICS, TOYAMA, JAPAN

Manfred Kahn

At the Third U.S.–Japan Seminar on Dielectric and Piezoelectric Ceramics, the latest developments in these areas of ceramic technology were discussed. Papers were presented on the following topics: electronic films, processing, barium titanate analysis and dielectric compositions, dielectrics for nickel electrode multilayer capacitors, capacitor reliability, microwave materials, anisotropic materials, relaxors and piezoelectric materials, piezoelectric transducers, piezoelectric applications, varistors, substrates and mechanical properties, photovoltaics, and modeling.

EDITOR'S NOTE

Manfred Kahn visited Japan during November 1986 to attend the Third U.S.–Japan Seminar on Dielectric and Piezoelectric Ceramics. During the seminar he also attended a panel meeting on piezoelectrics. Dr. Kahn evaluates some of the contributed papers; presents some notes from the panel meeting; discusses some of the research activities at the University of Tokyo; and offers his impressions from site visits to Sony Corporation's central laboratory, TDK's capacitor plants, and NGK's spark plug plant.

INTRODUCTORY REMARKS

In his keynote address, Cross (Pennsylvania State University) proposed that unique and useful phenomena will be derived through investigating and optimizing ferroelectric behavior in extremely thin and small regions, following the example of semiconductor technology. Scaling down to "micro" and "nano" subdomain microstructures is presently not adequately understood, but contrary to present interpretations, polar micro regions may well be possible. "Normal" ceramic surfaces are thought to be highly disordered, but with the advent of technologies such as vapor phase chemical deposition (CVD), the implementation of atomic order on surfaces can well lead to the verification of very short range ferroelectric phenomena. Ferroelectric nanocomposites in the range of 200 to 1,000 Angstroms may become feasible. Artificial superlattice structures could then stabilize metastable configurations with shallow potential atomic energy wells. This could give large atomic displacements, providing high pyro and piezoelectric sensitivities and even positioners with atomic accuracy.

Ichinose (Waseda University) discussed the efforts of four manufacturers to develop and market lead silicate borate glass, filled with 30 to 60 percent of alumina as thermal substrate material, similar to what is being worked on by Du Pont in the United States. Maximum density is attained between 800 and 900 °C. He also described the well-known silicon carbide beryllium oxide doped substrate material (pioneered and publicized by Hitachi) as well as a pressureless sintered, aluminum nitride composition, marketed under the name of Super Shapal by Toyo Soda Manuacturing Co., Ltd. This material is almost 85 percent translucent to visible light and transparent to infrared. Reduction of the oxygen content of both silicon carbide and aluminum nitride powders to below 1 percent is thought to be the cause for significantly enhanced thermal conductances.

Ichinose also mentioned work on diamond CVD coatings and showed a number of schematics of piezoelectric ultrasonic motors, using both stationary as well as propagating waves. He also showed a design that used a magnet to couple piezoelectric motion into a rotor. Efficiencies of 80 percent were quoted.

Sakabe (Murata Manufacturing Co., Ltd.) reviewed the properties of low-fired, stable K materials and relaxor-based dielectrics that contain ZnO. The materials he discussed are used in Japan in large-scale production, including multilayer capacitors with nickel electrodes, having capacities up to 400 µF that are made at a rate of up to 20 million capacitors per week.

Murata Manufacturing is also making internal boundary layer capacitors of strontium titanate and is reporting effective dielectric constants to 200,000. This is attained by making an ohmic rather than a junction contact to the ceramic and is implemented by indiffusion of aluminum. In closing, Sakabe mentioned that Murata Manufacturing is conducting a substantial effort in 10-GHz dielectric resonators for applications in direct broadcast satellite receivers. Q values above 8,000 at 10 GHz with very low temperature coefficients are attained. Results giving even higher experimental Q values are discussed in the contributed papers. Murata Manufacturing's basic thrust is to obtain higher dielectric constants to lower resonator size without a significant reduction in high frequency Q values.

CONTRIBUTED PAPERS

Electronic Films

The preparation of single crystal or ferroelectric thin films is presently one of the most advanced areas of electronic materials research. Japanese researchers reported primarily on the use of sophisticated instrumental film forming methods, whereas applications of chemistry (i.e., sol gel and organometallics) were reported by U.S. workers.

Matsubara (NEC Corp.) reported on the CVD deposition of $MgAl_2O_4$ epitaxial films on top of N type single xtal silicon wafers. Onto these, Matsubara RF-magnetron sputtered lead lanthanum zirconate (PLZT) films, which again grew epitaxially on top of the $MgAl_2O_4$ substrate layer. The films showed single crystal structure, using reflection high energy electron diffraction (RHEED). The lattice constants varied with the lanthanum content.

Wasa (Matsushita Electric Industry Co., Ltd.) discussed results from magnetron sputtering of PLZT onto sapphire substrates. His films were polycrystalline and showed a maximum dielectric constant of about 500 with 10 percent lanthanum. Changes in deposited stoichiometry due to the high substrate temperatures (500 to 700 °C) were mentioned.

Vest (Purdue University) reported on ferroelectrics from metalorganic precursors. "Defect-free" lead titanate and lead strontium titanate films, covering 2- by 2-cm areas with near theoretical density, were reported. He indicated that fast drying is necessary in these materials to obtain precipitation from the liquid without prior gel formation. The films have to be made thin to prevent cracking from drying shrinkage. Multiple, superimposed film applications are possible.

Payne (University of Illinois) discussed his spinned-on and fired lead titanate alkoxide based films. Metal methoxyethoxide solutions were spin cast on smooth substrates and densified at 700 °C. High-quality ferroelectric properties were shown in 1-µm thin films. This demonstrates a high degree of order and crystallization after firing at relatively low temperatures. The

films were able to withstand 100 V/µm, which permits their application as memory devices.

Processing

One of the more intriguing presentations at the seminar was by Shiosaki (Kyoto University) on laser-activated grain boundary etching. More conventionally, there were some interesting analyses of surface chemistry phenomena and their effects on dispersion and packing.

Shiosaki told of a novel ceramic drilling technique. A KOH solution covering a lead zirconate (PZT) ceramic is excited by a laser and whole grains are removed in the irradiated area. The progression rate with a 1-watt laser is more than 100 µm/s. The ceramic constituting the walls of the hole did not appear damaged. X-ray diffraction of the residue verified that whole grains had been removed out of the ceramic. Many ceramic formulations have been successfully drilled, using a self-imaging focusing mechanism. The latter derived its input from the acoustic noise generated during laser irradiation in a PZT plate that supports the sample. The hole drilled is not fully cylindrical, but a clean pattern can be generated.

Hirano (Nagoya University) reported on the synthesis of a 0.3-µm monodispersed and monosized spherical particle suspension of zirconium titanium stannate, derived from alkoxides. These materials had been sintered in the past only with the help of sintering additives such as zinc, nickel, iron, or lanthanum oxides. They have desirable 10-GHz properties for applications in direct broadcast satellite receivers and telecommunications. Hirano's work was aimed at making fine powders that could be sintered without sintering aids, thereby attaining higher Q values.

Hirano mixed liquid alkoxide derived precursors and partially described rather critical hydrolysis and multiple refluxing conditions that gave the desired monosized and monodispersed spherical particles. The particles were dried by filtering on a 0.01-µm filter (made by the Toyo Roshi Company Ltd. in Tokyo) and fired to relative densities of >96 percent with Q values up to 5,300 at 10 GHz without any sintering aids. He felt that the application of high compacting pressures to deagglomerate fine particles can be counterproductive, as it introduces strains in the material that give rise to excessive grain growth. The latter has been shown conclusively for hot pressed materials. The application of zeta potential titrations and other measurements indicate that base acid surface reactions are not as reversible as is often assumed. For instance, H^+ atoms that are attached to a bismuth oxide surface during acid treatment are not replaced by OH molecules in a basic environment but remain there and form "complexes" with OHs on adjacent sides. This model may be somewhat approximate, but evidence pointing to nonreversibility of surface reactions has been observed elsewhere. This may be the reason that most practical dispersant systems have steric characteristics, relying also on a polymer rather than just on the surface charge for dispersion. The nonreversibility of surface reactions makes it necessary to control the electrochemical environment (i.e., the optimum pH level, as established by previous zeta potential titrations) right from the time a powder is originally synthesized through all stages of processing. This then permits purely electrostatic repulsion to dominate and provide complete dispersion, negating the need for steric dispersion polymers.

Ueyama (Hitachi Chemical Co., Ltd.) showed a linear increase in packing density of both alumina and of

barium titanate particles as agglomerate size is reduced. The theoretical green density calculated from monosized 8-coordinated spheres is obtained as agglomerates are eliminated. The primary particle size is then measured. The same monosized particles show a small decrease in packing density when the concentration of polymethyl methacrylate (PMMA) binder is reduced from the minimum void volume (about 12 percent) to lower values. The group at Hitachi also investigated the effect of agglomerate size and binder concentration on the sintered density of barium titanate. They found that e. mination of agglomerates gave lower temperatures of surface densification. Agglomerate-free barium titanate attained a ceramic density of 5.8 g/cm^3 independent of binder concentration or of green packing density.

Levinson presented results from General Electric's laser patterning interconnecting work pertaining to the optimum composition of the polymer that carries the wiring. This is to adjust its absorption coefficient for the laser light to maximize the etch rate. A peak in the etch-depth-per-pulse versus absorption coefficient curve was found.

Barium Titanate Analysis and Dielectric Compositions

Smyth (Lehigh University) showed that the site occupation preference of trivalent impurities in barium titanate depends both on ionic size as well as on the stoichiometry of the matrix. Yttrium and erbium have the most intermediate ionic size, and they show a variable site occupation preference, most strongly determined by the stoichiometry of the matrix. Smyth showed some self-compensation when barium titanate is doped with yttrium. This is indicated when the valley in the resistivity versus dopant concentration curve is shifted to significantly higher concentrations, also causing the curve itself to be significantly broader. On the other hand, the full, theoretically expected self-compensation due to simultaneous occupancy of both the A and B sites is only rarely (if ever) observed.

Buchanan (University of Illinois) reported that the addition of zirconia to barium titanate gave (after firing below 1,300 °C) grain-growth-inhibited ceramic with the zirconia at the grain boundaries. At higher temperatures grains grew and zirconia was found in the lattice. The addition of calcium alumina borate flux gave sintering temperatures below 1,175 °C. Fluxing was said to allow diffusion of zirconia. Buchanan observed a zirconia induced Curie point shift, without grain growth above 1 μm. Evidence of boron in the grain bulk under these conditions was also claimed.

Burn (E.I. du Pont de Nemours & Co.) discussed a low-fire K 10,000 Z5U formulation that is precalcined with a small amount of lead. It does not contain additions of bismuth, cadmium fluoride, or other volatiles. Burn's results are achieved through close control of A/B stoichiometry and a precise donor/acceptor balance. Conduction is said to be electronic. Burn uses a new submicron barium titanate powder and the system is fired at 1,100 °C. Seventy-percent silver electrodes are used.

Takabatake (Asahi Glass Co.) reported on glassy films having a dielectric constant of 6.5 at 100 kHz. They are intended to provide a low temperature fired multilayer technology for hybrid circuits. The glass-ceramic contains alumina, which does not react at 900 °C, plus 2 $MgO \cdot SiO_2$. When the latter dissolves, it causes the boron in the glass to react with the alumina, giving the glass a high resistance to corrosion by water. A similar system has been made in the United States.

Abe (Sakai Chemical Industry Co., Ltd.) prepared barium titanate powder using hydrothermal synthesis. The desired 1,000 °C sintering temperature was achieved through doping with additives.

Dielectrics for Nickel Electrode Multilayer Capacitors

The volume of nickel electrode multilayer capacitors made in quality-conscious Japan tends to contradict U.S. manufacturers' claims that such devices cannot be made reliably. The history of this product should certainly set one to think.

The paper by Sakabe (Murata Manufacturing Co., Ltd.) on barium titanate based capacitors with internal nickel electrodes illustrates the application of Japanese engineering to results of U.S. science: One of his compositions appears to be an acceptor-doped, slightly barium rich, 10-percent calcium containing Z5U material, very similar to that put together and patented by Smyth and Error in the late 1960s. Murata Manufacturing got a patent (in 1976) on the calcium addition, but the function and site occupancy of the calcium addition have been described by Smyth. Murata Manufacturing fires at relatively low oxygen pressures (10^{-11} atm PO_2) to prevent loss of capacitance control due to nickel oxide diffusion. The significant part about all of this is that at least three U.S. multilayer capacitor manufacturers tried to introduce nickel electrode capacitors into the U.S. market. Their lack of success has to be at least in part attributed to an insufficient willingness to make the required investment in engineering the system. This resulted in the premature marketing of devices that had inadequate life test performance. It appears that Japanese perseverance led in this case to a new product line, i.e., to what they claim are economical and reliable substitutes for 1- to 100-mF tantalum capacitors.

Sakabe also mentioned a set of NPO and X7R formulations that are compatible with nickel electrodes. Again, a lot of early work was done on these in the U.S.

Kishi (Taiyo Yuden Co., Ltd.) added 3 percent of an unspecified, akaline earth containing lithium silicate glass to 1,220 °C solid-state-reacted barium titanate powder. It acted as a low-temperature flux, lowering the sintering temperature to below 1,200 °C and also provided acceptor doping to the matrix. "Reliable" nickel electrode multilayer capacitors are presumably made from this. The behavior of both Z5U as well as X7R was described. No postcalcining milling was mentioned.

Fujikawa (Kyocera Corp.) reported on X7R nickel electrode multilayer capacitors containing $CaZrO_3$, Y_2O_3, and about 0.5 percent MnO.

Capacitor Reliability

Three U.S. papers on this subject illustrate the present U.S. concern and Office of Naval Research sponsorship of this subject. It should be noted, though, that the first paper I ever saw discussing cracks leading to low voltage failures (blaming chlorine from CCl_4 degreasing fluid) came from Japan. Also, TDK is doing in-house work on understanding the causes for delaminations.

Anderson (University of Missouri-Rolla) subjected multilayer capacitors to a 770 °C temperature gradient, whereupon they developed interelectrode cracks. These capacitors were then subjected to voltage and temperature testing. The currents he observed were strictly related to the presence of humidity and to voltages above 0.5 volt. Lower voltages or the elimination of humidity (either by heating or by drying) resulted in low currents. He therefore concluded that electrolytic conduction is responsible for "low voltage failures" since high

voltages could dry out the cracks. No phenomena that could be related to the growth of metallic dendrites were observed.

Burton (Virginia Polytechnic Institute and State University) showed a conductivity peak in $BaTiO_3$ in the ohmic (low voltage) regime, near the cubic to tetragonal inversion temperature.

Dougherty (Advanced Materials Technologies) calculated the heat rise in a typical multilayer capacitor due to hysteresis losses from ac voltages. He found that 12 volts rms can heat a typical capacitor chip at a rate of >30 °C/s up to 130 to 140 °C. In a cold ambient environment this can develop stresses up to 400 kg/m within 10 seconds.

Microwave Materials

The Japanese developments described in this section are a direct outcome of an initiative by the Japanese government, i.e., the previously noted installation of satellites for direct broadcast TV. These materials transcend earlier U.S.-developed microwave dielectrics, both in time as well as in performance.

Tamura (Murata Manufacturing Co.) reported on $Ba(Mg_{1/3}Ta_{2/3})O_3$ that develops a high Q value due to MgTa ordering and the subsequent development of a hexagonal superstructure. It appears from infrared spectrum examinations that a strong c/a bond-strength anisotropy contributes to the higher Q values. More sinterability was provided by adding 10 percent $BaSnO_3$ to the material. This raised the Q value even more, though the superlattice lines tended to disappear. Q values of 20,000 with K values of 24 were seen at 10 GHz.

Murata Manufacturing is pioneering the application of infrared spectrum analysis to improve electrical properties of electronic ceramics (Wakino, Murata, and Tamura, 1986).

Murano (Sony Corp.) discussed the addition of ≦2 percent Co to $PbZrO_3$ to improve its properties as a dielectric resonator. Conventional solid-state reaction techniques were used. After some material optimization and after using a disk of $SrTiO_3$-NiO-Nb_2O_5 in series with it, a relatively high microwave device K (170) with a Q value of 1,200 was obtained.

Sato (OKI Electric Industry Co., Ltd.) worked on a complex rare earth, barium polytitanate composition that gave a slightly higher Q value (1,800) with about half the dielectric constant than the material shown by Murano. He claimed etchability as an advantage for electrode plating.

Anisotropic Materials

Kimura and Yamaguchi (Keio University) used molten salt synthesis to make rodlike potassium strontium niobate crystallites. The spontaneous polarization in these is parallel to the major axis of the rods, and after extrusion these rods were quite well aligned. X-ray diffraction of sintered compacts shows a very high degree of anisotropy. Similar techniques had been applied to barium titanate and gave a 40-percent improvement in maximum d_{33}.

Nagata (National Defense Academy) prepared an oriented $Pb_5Ge_3O_{11}$ type ceramic by adding silica to the base composition. During hot pressing a glass is formed; this then recrystallizes with the c-axis normal to the pressing direction. A highly anisotropic ceramic results with a maximum pyroelectric coefficient of 15×10^{-2} $\mu C/cm^2 {}^\circ C$, about three times that found in calcium-stabilized $PbTiO_3$. A g_{33} response as high as in PZT was mentioned.

Relaxors and Piezoelectric Materials

In these materials a high dielectric constant as well as anisotropy of the coupling factors is a desired

parameter, similar to what is being investigated in the U.S. In addition, previous Japanese work tends to indicate that perovskite lead zinc niobate could exhibit rather high piezoelectric activity.

Harmer (Lehigh University) reported on transmission electron microscopy of lead scandium tantalate and lead magnesium niobate samples. Superlattice reflections, indicating short-range order of magnesium and niobium ions, were found, even in what were thought to be disordered materials. The electrostatic charge imbalance kept the ordered domains from growing.

Schulze (Alfred University) analyzed lead magnesium niobate (PMN) with excess magnesia and found a high dielectric constant, even though the excess magnesia seemed to be concentrated near the grain boundaries. An effect of the magnesia on the ordering of the PMN structure is suspected.

Inagaki (Marucon Electronics Co., Ltd.) showed that barium and titanium can stabilize the perovskite structure in lead zinc niobate. Barium stabilization has been published previously.

Ichinose (Waseda University) added as much as 35 mole percent calcium (as well as Ba and Sr) to $PbTiO_3$ and found a peak in the spontaneous polarization of 42 $\mu C/cm^2$ with a K_t of 55 percent and a Curie point downshift of 400 °C. The maximum K_t/K_p ratio was at 25 percent calcium.

Sakata (Science University of Tokyo) investigated lead zirconate-lead tin zinc niobates and obtained relatively dense samples, having dielectric constants below 400 and a significant anisotropy of the coupling factors. The d_{33} values were near 42, the d_{31} values were about 8.5, and the d_{15} values were near 150. The material seems to be an improvement over lead titanate for high-frequency pulse applications.

Honda (Mitsubishi Electric Corp.) inhibited the grain growth and increased the sinterability of sodium lithium niobate through the addition of 0.5 percent alumina. Dielectric constants of 110 and coupling coefficients of 42 percent make this material useful for high-frequency pulse applications.

Tashiro (National Defense Academy) investigated piezoelectric and mechanical properties of lead bismuth sodium iron niobate-lead titanate solid solutions as a function of lead titanate content. The material has a significant anisotropy of its electromechanical coupling factors. The behavior is similar to that of lead titanate ceramic sintered through doping with calcium, samarium, or lanthanum. The author finds a close correlation between K_p and Poisson's ratio, even though he realizes that trying to relate a ratio to a constant can be a problem.

Piezoelectric Transducers

Uchino (Sophia University) presented the construction of a monomorph that used barium titanate reduced to a resistivity of about 10^8 Ω•cm. When coated with a surface barrier electrode, it showed as much as 100 μm deflection with an applied field and it exhibited mechanical resonances that also make it useful for buzzer and pump applications. This was one of the more ingenious devices shown at this meeting.

Sakai (Toyo Soda Manufacturing Co., Ltd.) also showed a barium titanate based monomorph. It was initially reduced to semiconductivity and was then partially reoxidized in from the surface to get a conductivity gradient and thereby (with voltage) a bending moment. The processing used is similar to that applied to a high-voltage, fine-grained barium titanate, surface-barrier-type capacitor.

In my paper, preparation and performance parameters of PZT 5A with photolithographically defined ordered void structures were discussed. A hydrostatic sensing gain of 199 dB ± 3.5 dB up to 250 kHz was shown. The factors leading to enhanced tensile fracture strengths and fracture energies of these were also discussed.

Takeuchi (Hitachi Ltd.) evaluated the response of 1-3 PZT/polymer composites as a function of PZT pillar size and volume fraction. Coupling factors (K_p) as high as 0.38 appear to make this configuration useful in the planar vibrational mode as well as in the flexure mode. The latter could find use in a lower acoustic impedance piezoelectric speaker.

Auld (Stanford University) discussed design parameters for composite transducers that can lead to the suppression of lateral resonances. This is done by using a superlattice period in the composite that gives rise to wide, lateral frequency stop bands.

Jomura (Hitachi Metals Ltd.) discussed mechanisms for increasing the available strains in a ceramic, e.g., by volume changes caused by phase transitions. Transverse strains as high as 0.1 percent at 10 kV/cm were mentioned.

Abe (Toshiba Corp.) discussed a polynomial expansion of the electric field in terms of the polarization, applied to determine the temperature coefficient of the electrostriction for a "modified lead zinc niobate ceramic."

Piezoelectric Applications

Ting (U.S. Naval Research Laboratory) reported on a 6- by 6-foot hydrophone array that was made up of 5-inch-square elements of polyvinylidene fluoride (PVDF) encapsulated in flexible polyurethane. The disadvantages of this material are its loss of piezoelectric sensitivity at 60 °C, its low dielectric constant, and its planar anisotropy. He also mentioned VDF-TrFE copolymers that are relatively stable up to 85 °C. Ting discussed the performance of a 1-3 composite made by Plessey Australia Ltd. that was said to have a g_h as high as 40 mVm/N with changes of only 3 dB under static pressures to 35 MPa.

Takahashi and Yoshiura (both from NEC Corp.), in two separate papers on piezoelectric ceramic actuators, described the advantages of a piezoelectric tape puncher in which small size actuators are mounted in close proximity: it is relatively silent and, with the inductive source described by Takahashi, requires very little energy for operation.

Chubachi (Tohoku University) continues to develop his line focus beam acoustic microscope. It tests local variations in elastic properties of a surface at 225 MHz. Significant differences in propagation velocity were shown across a PZT ceramic wafer. This is a sophisticated system that appears essential to make high quality surface acoustic wave devices.

Varistors

Masuyama (Taiyo Yuden Co., Ltd.) discussed electrical properties of strontium calcium titanate based varistors, indicating that lower oxygen pressure results in lower bulk resistivities. Indiffusion of sodium oxide gives varistors higher alpha at larger currents and therefore a larger surge energy absorbing capability.

Substrates and Mechanical Properties

Takahashi (Toshiba Corp.) showed data on the use of yttrium oxide as a sintering aid in aluminum nitrate. Its quantity has to be closely controlled, but it is claimed that if the oxygen content is kept below 1 percent, two to three times the thermal conductivity of aluminum nitrate that is hot pressed without a sintering aid can be achieved.

Niihara (National Defense Academy) discussed strength and fracture toughness of CVD-prepared silicon carbide. There was no glassy phase in the grain boundaries, and as a result the material had good high temperature strength. The CVD process conditions were manipulated to generate multiple stacking faults, and these faults were found to deflect cracks and increase fracture toughness considerably.

Yamamoto (National Defense Academy) determined stress magnitudes and anisotropies in various poled lead titanate and PZT compositions by measuring indentation crack lengths.

Kishimoto (University of Tokyo) presented an excellent piece of work on pure $BaTiO_3$ tapes that had been mechanically compressed after burnout. He showed that after firing he obtained a relatively flaw-free material, in which both electrical breakdown and mechanical bending test failures originated in the grain boundaries. This work had been preceded by high-temperature breakdown studies in MgO. There he found localized thermal breakdown channels and also lower breakdown strengths in single crystals in the presence of dislocations. He found even lower breakdown strengths in polycrystalline structures (Murata et al., 1985).

Photovoltaics

Uchino (Sophia University) described a relay that was activated by the photostrictive effect in PLZT: light generates charges at the surface of a bimorph. The charge accumulation causes a photovoltage and the high d_{33} of the poled PLZT then causes strain and a deflection of the PLZT. This was used to operate a snap switch. Illumination of an oppositely poled PLZT strip causes an opposite voltage that can be used to reverse the switch action. The high device impedance causes it to require 2 to 100 seconds for equilibriation.

Koepke (Honeywell Inc.) reported on a study of PLZT compositions designed to obtain optimum light switching. He found the lowest switching levels with Zr/Ti ratios of ≦65/35 and with ≦9.4 percent La.

Haertling (Motorola Inc.) reported on photoconductivity in biased PLZT. When voltage is used to close a PLZT shutter to block strong light, polarization at the electrodes causes an internal bias that changes the resultant shutter characteristics.

Modeling

Banno (NGK Spark Plug Co., Ltd.) elaborated on his previously introduced cubes model for voids in ceramics. He introduced a shape factor to describe voids that are isotropic only in the X-Y direction and calculated electrical, mechanical, and piezoelectric properties for ceramics having porosities up to 15 percent. Interesting correlations to experimental data were shown for conventionally pressed materials, assuming nearly round pores, and for hot pressed materials, assuming an X-Y diameter twice times the Z thickness. This model could be used to determine average pore shape.

Kagegawa (Chiba University) showed a technique for determining compositional fluctuations from the width of x-ray diffraction lines. The calculation is based on the differences in line width obtained from different lattice spacings.

PANEL MEETING ON PIEZOELECTRICS

Professor Newnham did an outstanding job of initiating and encouraging discussion. It would be my recommendation, though, to try to schedule the panel in the future on the second or third day, so as to give the participants a chance to become better acquainted first. The following items were discussed:

1. There were some comments about making geometries with graded impedances, as one could get from filler concentration gradients in 0–3 composites.

2. PVDF material apparently has been a disappointment. Some of the shortcomings concern its high output impedance, its large transverse response, and its excessive flexibility, which could cause noise.

3. There was some discussion about the d_{31} parameter having imaginary as well as real components. Positive d_{31} values were measured in lead titanate at certain temperatures. There was also some discussion on the contribution of the electronic structure to the high polarization and Curie point of this material. Its anisotropy is particularly useful in high-frequency piezoelectric 1–3 arrays where the interaction between the individual elements in the transverse mode has to be minimized.

4. There was some discussion of the mechanisms that control the d_{31} parameter. One is the Poisson's ratio of the material and another one is caused by a high c/a ratio that can give rise to microcracks or microfissures that reduce the d_{31}/d_{33} ratio. Excessive poling voltages can do the same.

5. NEC was specifically quoted as having a strong position in the manufacture of low-cost piezoelectric motors. Hard piezoelectric materials with low hysteresis, low aging, and high mechanical toughness are generally preferable for this application. In addition, a high Q value increases the potential efficiency of the motor. This is critical in battery-powered applications. One also wants the highest possible strains. Ceramic compositions near phase boundaries, therefore, look most attractive, except that materials with strains in excess of 6 percent (i.e., bismuth ferrite) are self-destructing. Another approach is the use of electrostrictive phenomena, and consideration is being given to strain magnification through the preparation of nonhomogeneous devices.

6. Apparently there is a direct inverse relationship of the coupling factor (K_t/K_p) ratio to the ionic size of dopants in lead titanate. Doping with gadolinium gives the highest anisotropy, and doping with lanthanum gives the lowest anisotropy. Cobalt doping is an exception; it gives a relatively high anisotropy for its ionic size.

VISIT TO DR. YANAGIDA'S LABORATORY AT THE UNIVERSITY OF TOKYO

Professor Yanagida's group consists of about 30 people. They have constructed some relatively sophisticated systems for heat treating and testing of devices under complex conditions of gas composition and gas flow. They also have set up a rudimentary tape casting facility. The group is involved in a variety of activities:

1. They are trying to raise the anisotropy of barium titanate made from fibrous precursors by doctor blading, stacking, and firing thick films.

2. One of Dr. Yanagida's main interests is the development of materials for sensing applications. Table 1 summarizes some of his efforts in this area. His work on porous zinc oxide is continuing

with various electronic dopants so as to increase zinc oxide sensitivity and specificity.

3. They have investigated the PTCR effect and lattice parameters in barium titanate doped with neodymium. They have verified self-compensation (occupancy both of barium and titanium sites) at neodymium concentrations above 0.15 percent (Nakano, Choi, and Yanagida, 1985).

4. They have looked at additions of 0.5 to 10 percent of alumina to ZnO, zirconia, and strontium chloride to increase the conductivities of these systems. The responsible mechanisms range from lattice substitutions in ZnO to interfacial ionic conductivity of alumina particles in strontium chloride, calcium fluoride, and barium fluoride.

5. They have a program evaluating conductivity and weight loss behavior of single oxide systems (rock salt strucures), such as NiO, MgO, MnO, and others, that are amenable to modeling.

PLANT VISITS

Sony Corporation

At the central laboratory of the Sony Corporation, I was shown how Sony is attempting to increase the memory capacity of a laser disk by three orders of magnitude. This requires cooling the storage media to the temperature of liquid helium and frequency modulating the laser beam, allowing a readout at each spot at 1,000 different frequencies. This is made possible by the different environments of neighboring atoms into which die molecules in the storage media are frozen. The exact frequency response of each die molecule is determined by the force field generated by surrounding molecules.

Sony also had an impressive array of CVD reactors that are designed to control the gas flow to permit abrupt changes in the compositions of the deposited films. More informally we discussed technical information transfer. Information generated in the United States was quoted as being very useful, but information generated in Japan was said to have even more engineering content and show more applied results.

Tamura showed me yttrium garnet films grown by liquid phase epitaxy on top of a gadolinium gallium garnet substrate. Tunable filters were built out of these and grooves in their surfaces were said to almost eliminate higher order responses. The films were used in variable, high-frequency oscillators in communications equipment. At the same time I was also shown the operation of a magnetic bubble memory in which bubbles were moved from one location to another and also obliterated, all using an argon laser beam. The preferred locations for the bubbles were generated in liquid phase epitaxially grown yttrium garnet films by etching small square depressions into the surface of such films. The introduction of bismuth into this garnet provided it with a high Faraday rotation angle. This permitted optical readout of the state of the memory.

Tamura also showed me a piezoelectric bimorph that used a rather complex lead bismuth nickel zinc niobium titanium zirconate as the driving material. A "shim plate" between the two piezoelectric driving plates was made out of oriented carbon fibers. This carbon fiber plate has more than an order of magnitude anisotropy in its modulus. This removes the mounting constraint from the driver plate to become narrower as its length increases (because of its Poisson's

Table 1. Sensor Configurations

Sensitivity to	Sensor		Operating Temperature (°C)	Sensitivity	References
	Material	Configuration			
CO	CuO-ZnO	Mechanically contacting surfaces	260	(1.5 x current)/ (decade of PCO_2)	Nakamura et al., 1986
CO_2	Beta Al_2O_3 bulk	One electrode coated with $LiCO_3$	500	(40 mV)/(decade of PCO_2)	Ogata et al., 1986
Reducing gases	ZnO	Porous body Pt impregnated	400	25% residual change with 400 ppm C_3H_8	Saito et al., 1986
Relative humidity	$(Zn_{0.8}\ Ni_{0.22})O$	Sintered body ZnO exsolved around NiO grain cores[a]	25	4 x wet/dry voltage	Choi et al., 1986
Relative humidity	$ZnO-(Ni_{0.97}\ Li_{0.03})O$	Mechanically contacting surfaces	25	100 x wet/dry current	Marra et al., 1986

[a]800 °C for 336 h.

ratio). As a result of this, a 35- to 50-percent increase in bimorph deflection was claimed. This appears to be a well-thought-out remedy to a not always recognized limitation of bimorph operation.

TDK

At the TDK capacitor plants in Akita, Mr. Furukawa explained that they are mixing their raw materials in high-speed, plastic-coated, continuous-flow disk mills, with the material recirculated two or three times until the right particle size is measured (on a Leeds and Northrop microtrack). The material is then filtered and calcined in Saggers. At least for disk capacitor preparation the material is then spray dried.

TDK makes 560 million disks a month. Thinner disks are made by punching sheets; heavier parts are made by rotary pressing. On the surface TDK's in-line lead forming and disk assembly machines look very similar to equipment used more than 20 years ago in the now almost defunct U.S. disk capacitor industry.

Some changes included a novel soldering approach where only the leads were dipped into the solder pot and the solder ball that accumulated on each lead end was used to provide solder when sweating the leads to the disks. Two cleaning and coating stations were also included with each assembly machine. An automatic outline inspection machine using video cameras was also used. The only significant amount of manpower in the whole line was at final packaging where the capacitor strips were respooled from the large wheels used in the line to small packaging wheels. At that location a person inserted capacitors by hand into the empty spots on the belt where previously rejects had been pulled out by the test machines.

One reason for TDK's success in building and maintaining disk manufacturing operation is probably its local customer base. Disk capacitors are largely used in the assembly of entertainment equipment, of which there is practically none left in the U.S. It appears, though, that history has come a full circle, as part of the Japanese disk manufacturing operations is being transferred elsewhere because of lower labor costs and because a market for disk capacitors has developed in other countries.

TDK is using three different methods for making multilayer capacitors. I was shown the most mature activity in which dielectric as well as electrode layers are laid down by screening. The latter operation plus the drying ovens as well as a return belt and the required substrate handling fixtures were all in one integral unit that was more than 15 feet long. Because drying is required after each screening cycle, the output of each machine is relatively low. I saw 32 of these machines. One operator is used for each four machines. The operators (who are fully gowned for dust reduction) seemed to spend most of their time cleaning screens from old setups and setting up for new configurations. As in most capacitor manufacturing, there is a significant number of different parts that have to be made. The equipment looked very clean and seemed to be running very smoothly, with lots of chrome plated and clean, painted surfaces in evidence. As in all manufacturing operations that I visited, everybody removed their shoes at the main entrance.

TDK used diamond wheels for dicing the green pads. This is slower but makes cleaner cuts than the blade dicing technique commonly used in the U.S. Automation of the dicing machines for X and Y cutting on the same machine was still being set up.

There was no smell from the binder solvent recovery operation nor from the burn-out ovens. TDK uses 2-day air burn-out in ovens, similar to what is practiced in the U.S.

Multilayer capacitor firing is done on zirconia slabs onto which the chips are loaded in a dense, single layer from an automatic loader. For termination of chips, four U.S.-made Palomar terminators were used. This was one of the few activities where there were a significant number of technicians attending an operation.

There was a room full of automatic chip sorting and testing machines. In another area there were a number of automated visual inspection machines in which dual video cameras hooked up to a computer were used to automatically inspect the outline of chip solder coverage from each side. Cartridges were used to feed the chips to and from the machine. Very low reject rates were observed in both operations.

TDK is also making a range of positive temperature coefficient resistor products including a line of honeycombs. TDK is trying to introduce these in clothes dryers and also in baseboard heater-type applications.

Kikuchi, an engineer at TDK, evaluated the acoustic response of honeycomb-shaped PZT material. He found the radial resonance reduced by a factor of 8 in magnitude from those in a solid disk. Harmonics of these are almost completely absent, and the thickness resonance was reduced in frequency by almost 30 percent. There is, furthermore, no indication of thickness harmonics. Stiffness and Q values are also less than in solid disks. The application of honeycomb-shaped PZT devices as effective underwater acoustic sources is under consideration.

In the afternoon Mr. Furukawa and Mr. Yahagi discussed their developmental work on compositions and grain size control of internal barrier layer strontium titanate based dielectrics: This is done by adjustments of stoichiometry and also by additions of manganese oxide and 10 percent calcium titanate. In addition, they seemed quite concerned about factors leading to delamination in multilayer capacitors. They are exclusively using 100-percent palladium electrodes with high-fired dielectric compositions. There seems to be an incipient development of silver bearing internal capacitor electrode systems. They showed thermogravimetric analysis (TGA) curves and suggested that the rapid weight loss at the temperature the palladium oxide becomes unstable may be the cause of their delamination problems. They had evolved a thermal shock testing technique that was said to be able to detect delaminated capacitors. They seem to be well aware of U.S. publications in this area. TDK seems to be relatively strong in equipment design; the engineering manager seems to be an expert in this area. TDK claimed to be able to sell chips at ¥2 each and make a profit. TDK's equipment was constructed like money was no object, with extended unattended operation to be one of the foremost design parameters. As noted, low output rates were compensated for by more machines.

In a different location (near Tokyo) TDK has a substantial hybrid circuit manufacturing operation. TDK uses 1-1/2 tons of silver paints a month and an unspecified amount of Birox resistor materials from Du Pont. Low-frequency as well as microwave hybrids are made in an automated assembly line. The assembly line has 30 automatic screeners with parts handled in cartridges, which permit automatic loading and feeding into processing equipment and kilns. The majority of these hybrids go into telecommunications applications.

TDK is also making varistors, both out of reduced and grain boundary oxidized strontium titanate as well as out of TiO_2. It appears that the TiO_2 based varistors have about twice the dissipation factor of strontium titanate based devices below 2 kHz, but at higher frequencies their loss is significantly less.

An interesting varistor application is a washerlike structure made by TDK with segmented electrodes. It is designed to be mounted behind and connected to the collector of fractional horsepower universal motors to suppress arcing and prolong brush life. Only a reliability conscious user of small motors could be expected to pay the required premium for such a feature.

NGK

Dr. Banno gave me a tour through the NGK spark plug plant. This facility is heavily automated. A substantial metal working plant uses relatively old German and American-made equipment to automatically make the metal parts for spark plugs. The material here is handled in bulk with manned forklifts moving large containers full of small parts. In the plating operation and in the ceramic preparation and assembly plant, 90 percent or more of material handling is automated.

The alumina is wet milled and spray dried. The spark plugs are hydrostatically pressed, sent through a curing cycle, cut and ground to shape, fired, marked, glazed, and fired again with very little human intervention in the process. Copper electrodes are used in the spark plugs, and nickel plating is applied to the business end of the electrode to provide erosion protection. Talcum is used for sealing the electrode to the insulator. A significantly larger fraction of the machinery on the floor is dedicated to handling, moving, and aligning the parts than to the operations themselves. It appears that careful design, construction, and upkeep of such equipment are at least in part responsible for the Japanese productivity. I saw relatively old equipment running unattended, with a multitude of interlocks and safety switches monitoring its operation. Apparently mechanical linkages and relay logic were broadly used to program the equipment.

NTK (an affiliate) is marketing a wide range of "fine" ceramic products. NTK has a broad line of 455-kHz piezoelectric bandpass filters and FM discriminators, 7- to 15-MHz frequency-control resonators, and piezoelectric ceramic-metal as well as ceramic-ceramic bimorph elements for audio tone generators. NTK also has an extensive line of piezoelectric ignitors. A number of piezoelectric transducers are made; some are finished into hydrophones and others are assembled into transmitters for both military as well as civilian applications. Piezoelectric oil level detectors, engine knock sensors, and both TiO_2 and zirconia oxygen-pressure measuring elements are also made. Furthermore, NTK has an extensive line of alumina insulators, heater supports, thread guides, metallized substrates for microcircuit packages as well as silicon carbide cutting tools, bearing elements, compressor rotors, and a variety of ceramic parts for air-cooled internal combustion engines. I was shown beta alumina, solid electrolyte batteries presumably designed for load leveling applications in electric power grids.

Murata Manufacturing

Wakino and coworkers discussed a metalorganic CVD technique for depositing tantalum oxide films. Dielectric constants of 26, with 4 to 6 MV/cm capability in a 100-Angstrom thickness, were mentioned. Tantalum ethylide $Ta(OC_2H_5)_3$ vapor was used in the presence of titanium $O(C_3H_7)_4$

vapors with the titania providing an acceptor in the tantalum oxide structure. Substrate temperatures above 650 °C caused film crystallization, but the dielectric strengths of the lower temperature amorphous films were higher than those that had been crystallized.

OKI Electric Industry Co.

Kamata showed me an assembly line where they are making about 20,000 sonobuoys a year. A substantial fraction of the assembly is done by hand, even though they have some automated material handling equipment. They use monomorphs as omnidirectional sensors. These consist of a thin ceramic disk mounted on a brass shim in an aluminum or plastic cup. This was used in addition to other, more conventional configurations. HQS 6B is presently the most popular type (70 percent of their output). The sonobuoys I saw in assembly used a seawater-actuated battery that was able to power the buoy for up to 8 hours (shorter times were programmable). The construction of the bimorph sensing element as well as of the sonobuoy itself did not appear to be hardened for elevated pressures or for shock loads.

SUMMARY

A U.S. manufacturer would find it nearly impossible to make a profit from a broad line of new devices with special materials, as I saw at NGK, without a more extensive and costly incubation time than is usually found acceptable. One must conclude, therefore, that Japanese implementation of some of these technologies is due to their use of other than early profitability criteria when they make decisions on the introduction of new products. The wide spread of their decision making process may contribute to this: a mid-level manager who (at least in Japan) is looking at a 15-year future with his employer is more apt to take the long view than a senior executive who is largely concerned with the reaction of stockholders.

Notwithstanding a low unemployment rate (by U.S. standards), there appears to be quite a sense of competition in Japan. It is not certain that people in Japanese industry work any harder than in the U.S., but Japanese professionals seem to be putting in longer hours. One cannot fail to be impressed by their factories. It appears that they have set out to do things the "right way" with a willingness to spend a rather substantial amount of money to obtain properly designed manufacturing equipment. It appears that because of a conceived high labor cost (that still may be lower than in the U.S.), the Japanese have improved their productivity by beating on banks and on machine designers in preference to beating on their production force.

They have automated many hard-to-mechanize material handling operations that manufacturers in the U.S. often find it more profitable to perform with manual labor. One is led to the conclusion that funds expended on equipment designers and model builders somehow carry much lower overhead adders than those expended for direct labor.

I saw numerous Japanese items for sale in the United States at lower prices than in Japan. This would imply that at least in 1986 Japanese manufacturers and traders exported merchandise at significantly lower profit margins than were extracted from sales within Japan.

The support of advanced technologies by the Japanese government takes many forms; for instance, as suitable sensors are being developed, their use is mandated universally (e.g., sensors for the presence of escaping cooking gas). Right now there seems to be some discussion on mandating the use of ceramic PTCR heaters instead of

nichrome in laundry dryers and even in space heaters. The lower surface temperatures of PTCR heaters reduce the fire hazard posed by dried lint, paper scraps, etc. These applications were considered in the United States more than 10 years ago but were rejected then, largely due to high material costs. There are a number of Japanese manufacturers who have now built up a significant PTCR manufacturing capability, and if the use of ceramic PTCR heaters is legislated, one could expect roughly a doubling in the tonnage of electronic ceramics produced in Japan (PTCR devices have a much larger mass than multilayer or even disk capacitors).

When looking at the scope of Japanese research, the breadth of their product lines (specifically in high tech ceramics), and their investment in automation and material handling, one is forced to conclude that many decisions on expenditures and investments are made with only small regard to the immediate return on the investment. One can easily infer that funds are made available for the sole purpose of advancing technology and raising productivity. The government then has a vested interest in supporting the market for new products, i.e., by legislation or by policies that lead to increased exports. With the recent downturn in Japanese exports, one can expect increased encouragement of internal Japanese consumption. The decision to initiate, for instance, direct satellite broadcasting in Japan has given rise to a considerable amount of activity towards the development and manufacture of microwave home satellite receivers. At 10-GHz frequencies receiving dishes can only be a little above 2 feet in diameter, and small, stable resonators are needed for local oscillator frequency control. They are presently transmitting on two channels, with excellent pictures. The use of even higher frequencies is envisioned. As noted, a significant amount of research in ceramic dielectrics is directly attributable to this decision.

Japan is still a land of contrasts. One sees people using abacuses, but in many areas one notices the penetration of advanced technology in consumer areas, e.g., hand calculators with graphics programs and displays, pay television in the backseat of taxi cabs, computerized wake-up calls in hotels, and other sophisticated consumer electronics.

REFERENCES

Choi, S.C., T. Saeki, K. Koumoto, and H. Yanagida. 1985. Humidity-sensing characteristics of the grain boundary-controlled NiO-ZnO ceramics. *The Chemical Society of Japan*, June, 1193-99.

Marra, R.A., Y. Nakamura, S. Fujitsu, and H. Yanagida. 1986. Humidity sensitive electrical conduction of ZnO-$Ni_{1-x}Li_xO$ heterocontacts. *Journal of the American Ceramic Society* 69 (July): C-143-45.

Murata, H., S.C. Choi, K. Koumoto, and H. Yanagida. 1985. High temperature electrical breakdown in single crystal and polycrystalline MgO. *Journal of Materials Science* 20:4507-13.

Nakamura, Y., A. Ando, T. Tsurutani, O. Okada, M. Miyayama, K. Koumoto, and H. Yanagida. 1986. Gas sensitivity of CuO/ZnO hetero-contact chemistry. *Letters of the Chemical Society of Japan*, April, 413-16.

Nakano, T., S.C. Choi, and H. Yanagida. 1985. Effect of Nd doping on the electrical conductivity and lattice parameters of barium-lead titanate. *Journal of the Korean Ceramic Society* 27(4): 15-20.

Ogata, T., S. Fujitsu, M. Miyayama, K. Koumoto, and H. Yanagida. 1986. Co_2 gas sensor using ß-Al_2O_3 and metal carbonate. *Journal of Materials Science Letters* 5 (May): 285–86.

Saito, S., M. Miyayama, K. Koumoto, and H. Yanagida. 1985. Gas sensing characteristics of porous ZnO and Pt/ZnO ceramics. *Journal of the American Ceramic Society* 68(1): 40–43.

Wakino, K., M. Murata, and H. Tamura. 1986. FAR infrared reflection spectra of Ba(Zn,Ta)O -$BaZrO_3$. *Journal of the American Cer mic Soc:ety* 69(1): 34–37.

Manfred Kahn received a BSEE degree from the University of Wisconsin, a MSEE degree from Rensselaer Polytechnic Institute, and a Ph.D. in ceramic science from Pennsylvania State University. Dr. Kahn worked for 20 years at Sprague Electric Company and for 8 years at AVX Ceramics in the electronic ceramics area. For 1 year he taught electrical engineering. Since 1983 he has been in charge of the Electronic Section in the Ceramics Branch of the Material Science and Technology Division of the Naval Research Laboratory in Washington, DC. Dr. Kahn is a Fellow of the American Ceramic Society. His current research interests include composites made from electronic ceramics.

VISITS TO SOME HEAT TRANSFER RESEARCH GROUPS IN JAPAN

Peter C. Wayner, Jr.

Several research institutes in Japan are vigorously pursuing improved products and enhanced processes by studying the physicochemical characteristics of heat transfer. At Keio University, an electric field is being used to enhance heat transfer. The research group at the Tokyo Institute of Technology is working on projects designed to improve the efficiency of high technology devices and processes. Thermal management of electronic equipment is being investigated at the Hitachi Mechanical Engineering Laboratory. At Tokyo University Institute of Industrial Science, convective heat transfer processes in a single crystal growth, dropwise condensation on a horizontal tube, and enhancement of heat transfer are being studied.

BACKGROUND

There has been a continuous growth in basic research on the small scale characteristics of heat transfer so that these phenomena can be effectively used to control the transport processes on which the success of many high technology processes and products depend. Within this realm, three key words are small-scale, interfacial phenomena, and enhancement. The objective of using the characteristics of interfacial phenomena is to enhance heat transfer in a natural (i.e., passive) way by using an interface with desirable characteristics. Citing an example, a boiling surface with an enhanced heat transfer coefficient can be attained by using well-designed nucleation sites at the liquid-solid interface. These surfaces currently have application in the cooling of electronic equipment. Due to current low energy costs, the objective of improving the efficiency and performance of high technology processes and products has replaced the efficient use of thermal energy as the primary interest of heat transfer research in many laboratories including the ones discussed below.

During the week of 2 February 1987, I had the opportunity to visit a set of laboratories in Japan well known for their research on the use of interfacial phenomena in heat transfer. The purpose of the visit, which is reported on herein, was to discuss research areas of mutual interest being pursued in Japan. The observations listed below are in chronological order.

KEIO UNIVERSITY

One of the augmentation techniques that Professor Yasuhiko H. Mori's research group at Keio University is emphasizing is the use of an electric field to enhance heat transfer. Heat transfer to a drop in a direct contact heat exchanger can be enhanced by applying an electric field that appears to induce intensive shear flow concentrated near the drop interface. The drop oscillations depend on the wave form of the electric field. They have found that a large interfacial tension is favorable for any mode because it allows large fields to be used while maintaining drop integrity (Mori, Ichikawa, and Kaji, 1987).

In keeping with his general interest in using electric fields, a transverse electric field is being used to augment heat transfer to a dielectric liquid flowing with laminar motion between two plates. In addition, the electrical augmentation of drying solutions or suspensions in the form of drops and particles has been proposed. It appears to work well for small particles but not for drops. Binary systems are being studied in many laboratories because interfacial shear stresses are enhanced and additional variables are present. In this case, the final spreading coefficient of a binary liquid-liquid-vapor system is being measured. The belief that the rheological nature of surface films can be used to enhance direct contact evaporation has led to a current study of this effect along with the study of evaporating drops in an immiscible fluid.

TOKYO INSTITUTE OF TECHNOLOGY

Professor Kunio Hijikata's research group at the Tokyo Institute of Technology is working on a number of research projects that are designed to improve the efficiency of high technology devices and processes. Multicomponent systems are being emphasized to reduce temperature differences in the case of thermal storage and, in the case of heat pipes, to obtain a sharp change in the heat flux with a small change in the temperature difference. The use of a binary mixture in a heat pipe leads to an improved "thermal diode effect." The combined use of interfacial phenomena and an electrical potential difference to enhance evaporation from a thin film is being evaluated in the study of evaporation from a meniscus attached to a raised horizontal wire. Evaporation in the contact line region of a very thin film is important. In a study of evaporation from grooved surfaces in which the contact line is very important, they have been able to demonstrate that a grooved surface having a right angle side wall shows the best performance among the various surfaces studied. In a related study on enhancement, an electric discharge is used to enhance mass transfer to a porous surface in catalytic combustion with good control over the process being attained. For the improvement of high technology processes, the study of microscale heat transfer is currently considered important (e.g., convective heat transfer in very small gaps, evaporation in the contact line region, the interference structures, and the measurement of very small temperature differences for the control and understanding of transport processes in very small regions like crystal growth).

HITACHI MECHANICAL ENGINEERING LABORATORY

A visit with Dr. Wataru Nakayama and Dr. Shigeki Hirasawa at the Mechanical Engineering Laboratory of Hitachi, Ltd. allowed discussions concerning current projects at their laboratory. The thermal management of electronic equipment is, of course, of interest to Hitachi. Dr. Nakayama, who has had a long interest in this area, has just published an excellent review article on the subject that includes many of his personal results in this area (Nakayama, 1986). His current research also includes the numerical analysis of the relationship between the growth of semiconductor single crystals and the thermal environment in a Czochralski apparatus (Nakayama and Masaki, 1986). Many of these results demonstrate the unique nature of heat transfer processes in high technology areas. Transport processes in the contact line region are of importance in various projects at Hitachi, Ltd. (e.g., in spin coating, rivulet flow on a heated

vertical wall, and in two-phase flow with boiling in microchannels). Current results on the effect of a dynamic contact angle on rivulet flow down a vertical heated wall are given in the article by Hirasawa and Haupmann (1986).

TOKYO UNIVERSITY INSTITUTE OF INDUSTRIAL SCIENCE

At the Institute of Industrial Science of the University of Tokyo, Professor Ichiro Tanasawa's research group is working on a variety of heat transfer topics associated with materials. The convective heat transfer processes in a single crystal growth are being studied using encapsulated liquid crystals to observe the temperature field. In order to form different metal structures, hot liquid metals in the form of drops are being rapidly solidified by dropping them into a column of cool liquid. The structure and properties of the solidified fragments of the shattered drops are correlated with the solidification rate. In the field of dropwise condensation on a horizontal tube, they have found that promoters have too short of a finite life (Tanasawa and Saito, 1987). Enhancement of heat transfer is also being studied; in this case the effect of turbulent promoters on flow in channels is being evaluated. Results on the effects of magnetic fields and gravity on Marangoni flows are reported by Maekawa and Tanasawa (1987). Also at the Institute of Technology, Dr. Shigefumi Nishio is directing a set of projects emphasizing interfacial effects with the following observed results:

- The boiling curve for helium can be modified using coated surfaces.
- The use of grooved surfaces in spray cooling leads to enhancement.
- The length of the heat transfer surface has a large effect on the heat transfer coefficient in film boiling on a vertical surface.

Current results on the use of mist cooling in the tempering of glass are presented in the article by Ohkubo and Nishio (1987).

CONCLUSION

In general, the research groups visited are vigorously pursuing improved products and enhanced processes by studying the physicochemical characteristics of heat transfer.

ACKNOWLEDGMENT

My sincerest appreciation goes to all the Japanese researchers I visited for their hospitality and frank discussions, which form the basis of this report.

REFERENCES

Hirasawa, S., and E.G. Haupmann, 1986. Dynamic contact angle of a rivulet flowing down a vertical heated wall. In *Proceedings of the Eighth International Heat Transfer Conference* 4:1877-82, 17-22 August, San Francisco, Calif. Hemisphere Publishing Co.

Maekawa, T., and I. Tanasawa. 1987. Effects of magnetic field and gravity on onset of Marangoni convection. In *Proceedings of the Second ASME-JSME Thermal Engineering Joint Conference*, 22-27 March, Honolulu, Hawaii.

Mori, Y.H., M. Ichikawa, and N. Kaji. 1987. An attempt at applying an electric field for enhancing direct liquid-liquid contact heat transfer in a spray column (Characteristics of formation and release of drops in steady or periodically-changing electric fields). In *Proceedings of the Second ASME-JSME Thermal Engineering Joint Conference*, 22-27 March, Honolulu, Hawaii.

Nakayama, W. 1986. Thermal management of electronic equipment: A review of technology and research topics. *Applied Mechanics Review* 39(12): 1847-68.

Nakayama, W., and M. Masaki. 1986. Influence of the thermal environment on the growth of single crystals in a Czochralski apparatus. In *Proceedings of the Eighth International Heat Transfer Conference* 4:1755-60, 17-22 August, San Francisco, Calif. Hemisphere Publishing Co.

Ohkubo, H., and S. Nishio. 1987. Mist cooling for thermal tempering of glass. In *Proceedings of the Second ASME-JSME Thermal Engineering Joint Conference*, 22-27 March, Honolulu, Hawaii.

Tanasawa, I., and M. Saito. 1987. Film and dropwise condensation of steam on a vertical bank of horizontal circular tubes. In *Proceedings of the Second ASME-JSME Thermal Engineering Joint Conference*, 22-27 March, Honolulu, Hawaii.

Peter C. Wayner, Jr. is a Professor of Chemical Engineering at Rensselaer Polytechnic Institute in Troy, New York. Dr. Wayner received a B.S. degree in 1956 from Rensselaer Polytechnic Institute, a M.S. degree in 1960 from Massachusetts Institute of Technology, and a Ph.D. degree in 1963 from Northwestern University, all in chemical engineering. His expertise in experimental and analytical interfacial phenomena and change-of-phase heat transfer is recognized worldwide due to the many contributions he has made during his 20-year career. Dr. Wayner was the 1985 Chairman of the Heat Transfer and Energy Conversion Division of the American Institute of Chemical Engineers. Currently, he is a Consulting Editor for Chemical Engineering Progress.

THE CHINESE INSTITUTE OF ELECTRONICS 1986 INTERNATIONAL CONFERENCE ON RADAR (CICR-86)

Robert S. Duggan, Jr.

This article highlights some of the key papers presented during the conference. Phased arrays, clutter discrimination, digital signal processing, spread spectrum, and ECCM were addressed. One key area missing was stealth technology—still considered by many countries, including China, to be a highly classified area. Although many western countries participated in this conference, two-thirds of the papers were presented by Chinese authors. Brief descriptions of the technical tours to the Nanjing Research Institute of Electronics Technology, the Nanjing Electronic Devices Research Institute, and the Radio Engineering Department of the Nanjing Institute of Technology are also included.

INTRODUCTION

The Chinese Institute of Electronics (CIE) 1986 International Conference on Radar was held at the Jinling Hotel, Nanjing, the People's Republic of China, on 4 to 7 November 1986. The General Chairman of the conference was Shen Zhongyi, a fellow of the CIE and a senior official of the Electronics Industry. Shen opened the conference with a welcoming address. Also making comments were Feng Shizhang of the Chinese Academy of Electronics Technology and Robert T. Hill, from the Aerospace and Electronic Systems Society of IEEE. The conference was divided into a number of sessions covering the following topics: radar systems (A1-A4), radar signal processing (B1-B2), array antennas (C1), antennas (C2), radar detection (B4), radar trackers and transmitters (D4 & D2), radar electronic counter countermeasures (ECCM) and waveform design (A5), servo-systems (D3), radar polarization (C4), radar imaging (A6), filter design (B5), microwave devices (C5), radar identification (A7), data processing (B6), and receivers (D1). The Appendix contains a list of the papers presented during these sessions. During the conference technical tours were arranged at three facilities: the Nanjing Research Institute of Electronics Technology, the Nanjing Electron Devices Institute, and the Radio Engineering Department of Nanjing Institute of Technology. This article highlights the papers presented during sessions A1 through A7 and presents information gathered during the technical tours.

SESSION HIGHLIGHTS

Session A1 (Radar Systems I)

Four invited papers were included in this first conference session. They were from the U.S., China, the U.K., and France. All except, unfortunately, the Chinese paper (A1-2) are included in the conference proceedings.

R.T. Hill (A1-1) discussed the importance of feedback control in radar system design. Feng Shizhang gave a survey paper (A1-2) on Chinese radar technology. The first Chinese radar was developed in Nanjing. The first Chinese three-dimensional radar used frequency scanning. China now has a C-band, 297-element phased array for space surveillance and tracking. They also have in use a P-band radar with over 800 elements and computer-controlled waveform T units, vertical polarization, log periodic antennas, 55-dB subclutter visibility, and digital filters with FFT. Instrumentation

radars have been designed for missile tracking from fixed, mobile, and shipboard platforms. J. Clarke, from the U.K., surveyed early warning radar development from World War II through the Nimrod airborne early warning (AEW) (A1-3). M.H. Carpentier, former president of SEE from Thomson-CSF in France, talked about how radar has evolved over the years—from flat surfaces to double-curved reflectors and now back to flat plates (A1-4). Asked what he sees in the future, he predicted more development in the millimeter bands of 90 and 150 GHz—and also in the 1- to 20-micron range. He also said that in spite of the efforts to reduce radar cross section, he did not foresee significant increases in radar power but rather more signal processing. Bandwidths may increase somewhat, but international regulations will probably prevent widespread use of carrier-free transmissions.

Session A2 (Radar Systems II)

Wang Yue, from the Xian Applied Electronics Technology Research Institute, described the Chinese Fire Control Radar #702 (A2-1). It uses dual frequencies (C and X bands), a Cassegrain antenna, dual-mode monopulse, chirp pulse compression in X band, pulse-to-pulse frequency agility over 16 frequencies, jittered pulse repetition frequency (prf), 35-dB sidelobe suppression, and a bandwidth of 1,000 MHz at X and 200 MHz at C.

J. Taylor of Westinghouse described Westinghouse's ASR-9 airport surveillance radar, designed for unattended operation with data fed over telephone lines to the operators (A2-2). It is planned by the FAA for 137 airports. There is much built-in test, and the mean-time-between-failure (MTBF) is greater than 1,500 hours.

Pan Puhua, from the Nanjing Marine Radar Institute, described China's Sea Eagle three-dimensional radar that uses mechanical azimuth and phase scanning in elevation (A2-3). Mounted atop the aft mast on a destroyer, the antenna is hydraulically stabilized in pitch and roll. Pan says electronic stabilization is the next step.

Wu Shaohu, from the Nanjing Research Institute of Electronics Technology (NRIET), in paper A2-7, described the mobile instrumentation radar HN-C03-M. It is at C band and is the latest in a series of instrumentation radars by NRIET. The mobile antenna is 3 to 6 meters in diameter, using a 5-horn monopulse Cassegrain design, handling both linear and circular polarization. The magnetron automatic frequency control (AFC) limits drift to ±1 MHz. Transmitter duty cycle is 0.001. A step prf is used to eliminate range ambiguities, with a range extending to 8,000 km. Peak power is 1 MW. Three of these radars have been built.

Session A3 (Radar Systems III)

D.H. Loppnow of ITT-Gilfillan, in paper A3-1, described the results of tests along the California coast using a Falcon C-band low level radar and the related communications system.

Wang Songshan, from Xian, described a special radar with wide angle phase scanning at X band using a special feed with a reflector-lens antenna (A3-2).

Ms. Wang Jun from NRIET, in paper A3-3, described research in an OTH HF radar, tracking a 707 and fighters from 790 to 1,500 km. Typical integration time for detection is about 16 seconds using 100-μs pulses for tracking the 707.

F.L. Graf from Philadelphia Electric (A3-4) described work with Georgia Tech and Geophysical Survey Systems in the use of radar to detect natural gas leaks. The dry gas changes soil characteristics, giving an indication of apparent difference in iron pipeline depth. Pulsed radar is preferred to FM/CW. Five systems are already in use in China. The radar uses several VHF/UHF frequencies at a prf of 50 kHz. The advent of plastic pipe makes detection more difficult, but even with plastic pipe considerable success has been achieved. Graf said subsurface sinkholes are "like a stealth bomber" to the radar. A symposium on ground penetrating radar is planned for Philadelphia in 1987.

Kuang Yongsheng from Duyun gave his paper (A3-6) on the JY-8 three-dimensional radar. Jiao Peinan, from the China Research Institute of Radiowave Propagation (CRIRP) in Xin Xiang, presented a paper (A3-7) on the operational availability of OTH radar, focusing on sunspots, aurora, and other natural problems that can inhibit the effectiveness of such HF radar. E.R. Billam from the U.K. gave a paper (C1-8) on optimizing phased array radar beam position separation.

Session A4 (Radar Systems IV)

Wang Beide, in paper A4-1, addressed the meteorological effects on air surveillance radars. Specifically, he addressed distortion of coverage, false echoes, and attenuation. He considers coverage distortion to be the most important.

Dan Yao, from the Northwest Telecommunications Engineering Institute (NWTEI) in Xian, discussed passive ranging, an ECCM technique against barrage jamming (A4-3). He described optimum correlation approaches that minimize equipment requirements.

Hans Lok from Sweden, in paper A4-4, described techniques for measuring radar cross section (RCS) of ships and other objects at sea.

Session A5 (Radar ECCM and Waveform Design)

In paper A5-6, Professor Lin Maoyung described optimum radar waveforms for pulling signals out of noise. This paper was based on M.S. theses by Shan Yueyan and Fan Zhengfang at the Beijing Institute of Technology (BIT) in 1985 and 1981, respectively.

Professor Du Jiangling from BIT, in paper A5-7, discussed his work trying to optimize the tradeoff between auto correlation sidelobe energy (ACSE), cross correlation energy (CCE), auto correlation sidelobe peak (ACSP), and cross correlation peak value (CCPV) of waveforms to help low probability of intercept (LPI) radar defeat anti-radiation missiles (ARMs). He found it is very difficult to optimize all four parameters simultaneously, but in this paper good properties of auto correlation and cross correlation are obtained. This was the subject of Professor Du's M.S. thesis this year at BIT.

Session A6 (Radar Imaging)

Professor Suzuki from Japan, in paper A6-5, described experiments in locating underground objects. Good results were obtained by moving the radar, somewhat like a synthetic aperture airborne radar. Pulse compression techniques also gave greatly increased resolution. Various modulation techniques, such as pseudo noise (PN) code and spread spectrum, have been used. Powers as low as 50 mW or so have been used with PN code—a much lower power than conventional radars (typically about 100 watts)

Some depths as shallow as 1.5 meters were shown, but up to 100 meters is possible. Applications for this technology include not only underground utilities but also locating objects covered by volcanic ash—a valuable tool also in archaeology. Various antennas have been tried for this, including resistance loaded triangular antennas, folded types, traveling wave types, etc. For shallow targets a pulse width of 1 ns is used. The largest pulse width is about 20 ns with a beam of 120°. The water content of the soil greatly affects the use of this technology.

In paper A6-6 Zhang Chengbo showed numerous photos made for remote sensing using synthetic aperture radar (SAR). He discussed his design work, which has been focused on techniques to reduce errors by the use of pulse compression and motion compensation. For 10 meters resolution a bandwidth of 30 MHz was used.

J.R. Wallington, from Marconi Defense Systems, described an approach to controlling target signatures, including infrared (IR), radar cross section (RCS), electromagnetic (EM) (other than radar cross section), and visual (emissions and reflectors) (A6-7). His principal focus related to RCS and the theoretical factors that affect detection as a function of target fluctuations. For example, by changing the fluctuations, an equivalent of 10 dB in RCS reduction may be achieved. Most of the talk related to generalities, since it obviously would have never been presented if it had used specific techniques for reducing signatures.

Session A7 (Radar Identification)

Dr. Malek Hussain of the University of Kuwait gave his paper (A7-2) on the use of a two-dimensional deconvolution algorithm for classifying targets and recognizing signals using nonsinusoidal radar signals. He described simulation of backscatter signals from aircraft. He concluded a scattering target can be modeled as a linear system and deconvolution can be used for target identification when dealing with carrier-free nonsinusoidal signals.

Gjessing's paper (A7-4) touched on some of Dr. Suzuki's work (A6-5) on underground object detection as well as detection and imaging of targets in sea clutter. Corsini's paper (A7-5) showed interesting results in three-dimensional image reconstruction of aircraft using coherent processing of radar echoes. Giuli (A7-7) addressed the use of polarization discriminants in target classification.

TECHNICAL TOURS

Nanjing Research Institute of Electronics Technology (NRIET)

This institute is in northern Nanjing. The sign at the entrance says Huaning Electronics Corporation. Huaning is apparently the production and marketing arm of NRIET. We were greeted by Zhang Guangyi, the vice director and chief engineer of NRIET. They have about 1,400 engineers and technicians, including 60 with Ph.D. degrees, with an additional 2,000 workers. The 16 research divisions include mechanical, microelectronic components (2), radar (2), signal processing, data processing, ferrites, antennas/propagation, and high power sources. NRIET is under the Academy of Electronics Technology. They use numerical control on some manufacturing. Multilayer boards of up to six layers are manufactured. They also assemble and test parabolic antennas.

Since the 1960s NRIET has been involved in both radar and radio broadcasting. They are active in satellite

and missile tracking; OTH radar; special instrumentation radar; very large phased array three-dimensional phase-scanning radar; microwave satellite communications; satcom equipment at C and Ku bands; color TV transmitters; FM transmitters; and a harbor surveillance X-band, 50-kW, 0.05-μs radar.

Hardware on display included MMIC with 0.2-mm lines and 0.3-mm spacing on alumina substrates. We also saw elements of an X-band noncoherent mobile missile/satellite tracking radar.

Nanjing Electronic Devices Research Institute (NEI)

This facility looked very familiar, though the name was not. We had previously visited here when it was the Nanjing Solid State Research Institute (NSSRI). It is south of East Zhong Shan Road, just inside the old Nanjing eastern gates. The work force is about 1,600, including 1,000 engineers and technicians. There are electronics and opto-electronics divisions. Research includes various vidicons, storage tubes, plasma, and electrochromic panel displays. Numerous product catalogs were obtained. Microwave devices included 4- to 6-mm GaAs mixers; Gunn diodes at 6 and 8 mm; X band; Impatt diodes; PIN diodes (22 to 26, 26 to 40, and 4 to 12.4 GHz); FET oscillators and power amplifiers (8 to 10 GHz); and parametric amplifiers at 3 and 6 GHz. When quizzed about their device applications at 4 and 6 mm, they were very vague, mumbling about remote sensing "perhaps."

Nanjing Institute of Technology (NIT), Radio Engineering Department

NIT is located about 2 km northeast of the Jinling Hotel. Our group was welcomed by NIT vice president Chen Do Xin. NIT was founded in 1904 and has 25,000 graduates. There are now 16 departments and 7,000 students including graduate students. There are 40 specialists and 35 research institutes. The faculty is about 600. Not only are various engineering disciplines covered but also management and social sciences. NIT is one of the top institutes in China. We were shown a film on their microelectronics center—which includes much computer-aided design—complementary metallic oxide semiconductor (CMOS) process, device, circuit, and logic simulation. Data base management is also used. Infrared is used in failure detection.

Professor Wang Yunyi (wife of the NIT president) and Associate Professor He Li Quan showed various devices—mixers and noise sources for Ku, Q, E, and W bands. Professors Chang Guo Xing and Lu showed other devices, including a 26- to 40-GHz pencil traveling wave tube (TWT), giving wider bandwidth than solid state. All the millimeter devices and related test equipment were locally made.

CONCLUSION

Of the 123 papers presented at this conference, 82 included Chinese authors—exactly two-thirds. Many western countries also participated, and the subjects were, for the most part, up-to-date and timely. Phased arrays, clutter discrimination, digital signal processing, spread spectrum, and ECCM were addressed. One key area essentially missing was stealth technology—perhaps the Chinese also still consider this a highly classified area.

The Chinese are a proud people, anxious to be treated as equals by the Western World. When a problem arose they were always anxious to resolve it, striving for respect and recognition in return for their resolution.

In conversations with various Chinese there was an obvious strong leaning towards the U.S. There are apparently now only about 200 Chinese studying in the U.S.S.R., while some 10,000 are studying in the U.S. The vast majority of Chinese National Aviation Corporation (CAAS) airplanes are now from the U.S.—mostly 737s, with 707s and 747s also in use. A few Ilyushin 18, Antonov 2, Antonov 12, Antonov 24, and Tu-154 aircraft are seen, but the U.S. dominates, along with some British Tridents and BAe 146s.

They are tilting evermore towards the West. The 50-to-1 ratio of their allocation of resources for university study (West versus Soviets) is a visible result of their admiration for the technology and educational systems of the West. China appears anxious to expand their involvement with the IEEE, and this should be encouraged.

I predict there will continue to be strong Chinese participation in the radar conferences of the future—in Britain, France, and Japan, as well as the U.S. We will do well to respect them and encourage even greater contact with the West. This will be of mutual benefit to all.

Robert S. Duggan, Jr., received his B.E.E. degree in 1951 and his M.S.E.E. degree in 1956 from Georgia Tech. Following service in Navy electronics, he performed research in radar and ECM at the Georgia Tech Engineering Experiment Station. Joining Lockheed in 1957, he has held a number of electronics staff and management positions involved with reconnaissance, mapping, countermeasures, and command/control programs. As Senior Staff Specialist, he now coordinates Lockheed's electronics R&D programs. Mr. Duggan is a member of Tau Beta Pi, Eta Kappa Nu, and Phi Kappa Phi. A Lieutenant Commander in the Naval Reserve (retired), he is a registered Professional Engineer in Georgia. He is an Associate Fellow of AIAA and is listed in various "Who's Who" listings. The author of numerous papers, he is the only engineer to have received both the Region 3 Outstanding Electrical Engineer Award (1976) and the Region 3 Outstanding Service Award (1980). He received the IEEE Centennial Medal in 1984. Mr. Duggan's current research interests include radar, countermeasures, reconnaissance, and C^3I.

Appendix

LIST OF PAPERS

SESSION A1—RADAR SYSTEMS I

A1–1 Radar tenacity, adaptivity and capacity and the importance of feedback control. *Robert T. Hill (U.S.).*

A1–2 Recent advance of radar technology in China. *Feng Shizhang (China).*

A1–3 The evolution of early warning radar in the United Kingdom. *John Clarke (U.K.).*

A1–4 Evolution of radar systems. *Michel H. Carpentier (France).*

SESSION A2—RADAR SYSTEMS II

A2–1 702 fire-control radar. *Wang Yue and Peng Jia-Ting (China).*

A2–2 Design of a new airport surveillance radar (ASR-9). *John W. Taylor, Jr. and Guntis Brunins (U.S.).*

A2–3 Missions and system selection of a shipborne 3-D radar. *Pan Puhua, Wu Yuankai, Zhang Jiasen, and Ou Yingji (China).*

A2–4 The evolution and application of multiple target tracking instrumentation radar. *Victor W. Hammond and Kenneth H. Wedge (U.S.).*

A2–5 Accurate modelling of glideslopes for instrument landing system. *M.M. Poulse, P.R. Mahapatra, and N. Balakrishnan (India).*

A2–6 Short range ground surveillance radar. *Albert Janex (France).*

A2–7 HN-C03-M mobile instrumentation radar. *Wu Shaohu (China).*

SESSION B1—RADAR SIGNAL PROCESSING I

B1–1 Bit-slice DBS digital signal processor. *Xie Chunwei and Chen Rong (China).*

B1–3 Fuzzy processing of radar signals. *Guo Guirong, Liang Taiji, Shen Qiang, and Zhuang Zhaowen (China).*

B1–4 Doppler frequency and its changing rate estimation by pulse pair processing or FFT techniques. *Shen Jianglin, Wang Li, and Qin Zhungyu (China).*

B1–5 Comparison of correlation coefficient estimators for real and complex Gaussian stationary processes. *Gaspare Galati and Paolo Ammendola (Italy).*

B1–6 Signal processing and digital filtering for multi-target measurement systems. *Zhang Zhiying and Weng Zuyin (China).*

B3–3 Group-complement code signal and its radar ambiguity function. *Zhong Chirui (China).*

B3–5 A new approach to the generation of polyphase coded signals. *Li Bingcheng and Qiang Bohan (China).*

SESSION C1—ARRAY ANTENNAS

C1–1 An investigation of near-field measurement for planar waveguide-fed slot arrays. *Fang Tongcheng (China).*

C1–3 Performance of circular aperture two step amplitude weighted arrays. *Guo Yanchang and Xue Fengzhang (China).*

C1–5 Application of 0–1 programming to mixed weighted linear arrays. *Wu Tienhai (China).*

C1–7 A C-band phased array dome antenna. *Xiong Jigun, Mei Guilan, and Chen Linmei (China).*

C3–1 Some practical problems in adaptive sidelobe cancellation. *Zhang Shouhong, Shen Fumin, and Bao Zheng (China).*

C3–2 Noise limitations on monopulse accuracy in a multibeam antenna. *J. Loraine and J.R. Wallington (U.K.).*

C3–3 Applications of digital open-loop sidelobe canceller to high-rotation-rate radar. *Lu Zhongliang, Liang Diannong, and Lee Qishun (China).*

SESSION A3—RADAR SYSTEMS III

A3–1 Coastal defense system surveillance with Falcon low level radar. *David H. Loppnow (U.S.).*

A3–2 Limited electronically scanned radar. *Wang Songshan and Zhu Fuxun (China).*

A3–3 HF sky-wave backscatter over-the-horizon radar. *Wang Jun and Wu Changgen (China).*

A3–4 Radar leak pinpointing. *Fred L. Graf (U.S.).*

A3–6 Some system designs of the JY-8 3-D radar. *Kuang Yongsheng (China).*

A3–7 The availability of OTH radar. *Jiao Peinan (China).*

C1–8 The optimization of beam position separation in phase array radar. *E.R. Billam (U.K.).*

SESSION B2—RADAR SIGNAL PROCESSING II

B2–3 A programmable MTD system with good performance. *Peng Yingning, Ma Zange, Ding Xiudong, Wang Xiutan, and Fu Jengyun (China).*

B2–5 Design of staggered MTI weightings in multi–clutters. *Yan Mingsheng and Mao Yuhai (China).*

B2–6 Modern techniques for the design and analysis of MTI filters. *Robert H. Fletcher (U.S.).*

B3–1 Quadraphase coded signal pulse compression. *Pan Wenbing, Yao Zhenxing, and Chen Wupeng (China).*

B3–2 Adaptive cancellation problems in predictive MTI (PAMTI). *F. Corsi, T. Bucciarelli, G. Picardi, and G. Riccobono (Italy).*

B3–4 False target problems in air traffic control radar beacon system. *Namio Mizuki and Nobuyuki Kaku (Japan).*

SESSION C2—ANTENNAS

C2–1 Mode analysis of wire antennas. *Cao Wei and Huang Xindi (China).*

C2–3 High performances printed radar antennas. *Albert Janex (France).*

C2–4 A receiving array of log–periodic dipoles. *Yang Rongxi, Huang Chibiao, and Xia Lianrong (China).*

C2–6 Analysis of the cross–dipole frequency selective surfaces. *Zhang Yifeng, Wang Shengchun, and Chen Xianjiang (China).*

C3–5 Final design and analysis of antenna structure. *Dong Ruoqi (China).*

C3–6 A GTD analysis of the near–field characteristics of multimode conical horns. *Zhu Siqi and Xie Tingfang (China).*

SESSION A4—RADAR SYSTEMS IV

A4–1 Meteorological effects on air surveillance radars. *Wang Beide (China).*

A4–2 Azimuth estimation techniques for monopulse SSR. *Antonio Di Vito, Gaspare Galati, and Giovanni Jacovitti (Italy).*

A4–3 Passive ranging by hyperbolic and direction finding. *Dan Yao and Feng Yiyun (China).*

A4–4 A calibration method for radar cross section measurements at sea. *Hans Lok (Sweden).*

A4–5 Application of the maintainable weighting configuration on reliability system design of radars. *Ding Dinghao (China).*

A4–6 Realisation of a low-cost high definition short range surveillance radar. *R.K. Arora (India).*

A4–7 The research of near-field scattering spectrum of radar targets by scaled modelling. *Chen Baohui (China).*

SESSION B4—RADAR DETECTION

B4–1 Robust detector for e-total variation finite samples. *Wang Zhong and Li Hong (China).*

B4–2 Radar detection of target signals in non-Gaussian clutter: Theory and applications. *A. Farina, A. Russo, and F. Scannapicco (Italy).*

B4–3 Adaptive radar CFAR detection in sea clutter using FFT processing. *Cui Ziyan (China) and Dr. D.C. Cooper (U.K.).*

B4–4 The performance comparison between parametric and non-parametric CFAR detectors in Weibull clutter. *Zhang Shayan, Mao Yuhai, and Fang Zaigen (China).*

B4–5 Direct evaluation of radar detection performance by calculating residue. *Hou Xiuying (China), N. Morinaga, and T. Namekawa (Japan).*

B4–6 Study on performance of nonparametric quantized rank detectors. *Zhu Zhaoda, Qiu Zhenming, and Zhang Xubao (China).*

B4–7 The detection performance and angular accuracy of ship targets for a ground-wave HF OTH radar. *Liu Yongtan, Shen Yiying, and Xu Rongqing (China).*

SESSIONS D4 & D2—RADAR TRACKERS & TRANSMITTERS

D4–1 A new type of automatic target-detection tracker. *Li Zhaopeng (China).*

D4–5 Maximum likelihood estimator to solve tracking radar multipath problems. *Giovanni Picardi and Roberto Seu (Italy).*

D2–1 High power solid state transmitter design for radar system. *Yu Nang Wong and Henry T. Lee (U.S.).*

D2–2 Transmitter for the all solid state radar. *Huang Weizhuo and Chen Zhencheng (China).*

D2–3 Solid state transmitters for modern radar applications. *Donald J. Hoft and Fuat Agi (U.S.).*

D2–4 A compact nanosecond pulse modulator. *Sha Jizhang, Xue Jianchao, and Qiang Bohan (China).*

D2–6 Analysis of quasi-active microwave pin diode limiter. *B.K. Sarkar (India).*

SESSION A5—RADAR ECCM AND WAVEFORM DESIGN

A5–1 The ECCM improvement factor (EIF): Illustrative examples, applications, and considerations in its utilization in radar ECCM performance assessment. *Stephen L. Johnston (U.S.).*

A5–2 Random FM–CW radar and its ECCM. *Liu Guosui, Shi Xiangquan, and Lu Jinhui (China).*

A5–4 CW radar with pseudo–random code phase modulation and sinusoidal frequency modulation. *Zhang Shinpo, Qi Lianbao, Sun Jintao, and Hong Jiaxiang (China).*

A5–5 A direct method of signal design for range–Doppler clutter rejection. *T.K. Bhattacharya, P.R. Mahapatra, and N. Balakrishnan (India).*

A5–6 On optimum radar waveforms for clutter rejection. *Shan Yueyan, Fan Zhengfang, and Lin Maoyung (China).*

A5–7 Waveform design for phase coded pulse compression radar with interpulse code agility. *Du Jiangling and Lin Maoyung (China).*

A8–2 Generation of a random sequence with specified distribution and spectrum. *Shen Jinyuan (China).*

SESSION D3—SERVO–SYSTEMS

D3–1 The study of the time–domain identification for radar servo–systems. *Wang Wenjun, Qu Shengli, and Chen Huaichen (China).*

D3–2 The analysis of tracking "blind zone" of two–axis antenna pedestal of naval fire control radar. *Song Jinglun and Zhang Jianzhong (China).*

D3–3 On–line identification in frequency–domain of the structure model of a radar servosystem. *Shang Xunxiu and Chen Huaichen (China).*

D3–4 The stability analysis of radar servosystems with mechanical parameters by describing function method. *Wu Fenggao and Liu Qiang (China).*

D3–5 Beam–stabilization and target–tracking for shipborne fire control radar. *Sun Bingsheng (China).*

D3–6 A method for finding low elevation angles with upper and lower beams. *Hu Shengen, Sun Maoyou, Sun Qixiou, and Tang Xingheng (China).*

D3–7 Position accuracy in multistatic radar. *Chen Hong and Ding Lufei (China).*

SESSION C4—RADAR POLARIZATION

C4–1 Theory of radar polarization. *Ke Youan (China).*

C4–2 Adaptive measurement of target maximum eigenpolarization. *Enzo Dalle Mese (Italy).*

C4–3 Analysis of instrumentation radar feed unit with changeable polarization. *Yuan Shingyuan andn Pan Zongda (China).*

C4–4 Development of a dual band monopulse antenna with changeable polarizations. *Chiu Chiaheng (China).*

C4–5 Experimental results on dual-polarization behavior of ground clutter. *M. Fossi, M. Gherardelli, P. Giannino, and D. Giuli (Italy).*

C3–7 Dielectric resonator stabilized GaAs FET oscillators. *Gu Molin and Liu Weishing (China).*

SESSION A6—RADAR IMAGING

A6–1 Ku-band system for 2-D microwave imaging array. *Xu Weiwu (China) and B.D. Steinberg (U.S.).*

A6–3 Three-dimensional microwave imaging in constrained space. *Li Xiaobe and Huang Shunji (China).*

A6–5 Advances subsurface radars. *Tsutomu Suzuki and Ikuo Arai (Japan).*

A6–6 Synthetic aperture radar design concept. *Zhang Chengbo (China).*

A6–7 An integrated approach to target signature management. *J.R. Wallington and P. Varnish (U.K.).*

A8–4 A programmable radar clutter simulator based on maximum entropy spectral estimation principle. *Hu Zengqian, Mao Yihai, and Peng Yingning (China).*

A8–5 A study for distribution of independent elements in CWLFM sampled sequence. *Wang Jinrong and Yuan Yieshu (China).*

SESSION B5—FILTER DESIGN

B5–1 The application of matched filter and "reversed" filter in coherent-on-receive system. *Zhang Peng and Sun Zhong Kang (China).*

B5–2 Analytical design of digital recursive filters with applications to signal detection and estimation. *J. Uebersfeld (France) and Weng Zuyin (China).*

B5–3 Optimum design of FIR filter's complex weight vector with real and imaginary parts in a reverse order. *Chen Xian and Li Xiangru (China).*

B5–4 Theoretical and experimental research of an adaptive clutter suppressing algorithm. *Cheng Dahai and Guo Guirong (China).*

B5–7 Sea clutter suppression in airborne radar systems. *J.C. Byrne, R.H. McLaughlin, P.A. Metherall, and F.B. Dyer (Canada and U.S.).*

D4–4 An adaptive tracking filter in a TWS radar. *Zhou Dong and Zhou Siyong (China).*

D4–6 Doppler acquisition and tracking techniques for an accelerating space launch vehicle. *K. Vendataraman, C.V. Rajaraman, and S. Babu (India).*

SESSION C5—MICROWAVE DEVICES

C5–1 Inhomogeneous plastic deformation and waveguide quality. *Yi Yinfei et al. (China).*

C5–2 Moment method analysis of orthogonal waveguides coupled by incline slots. *Wang Hanyang, Hu Shiming, and Wan Wei (China).*

C5–3 A simple dual function feed network. *Chang Zhiliang (China).*

C5–4 Microwave high power fast switching ferrite devices and their applications in radar. *Lin Lin (China).*

C5–5 Analysis of multiple-inductive posts in rectangular waveguide by method of lines. *Rong Aosheng and Li Sifan (China).*

C5–6 Study of correlative tolerances in the structural design of microwave components. *Zhou Guanjie (China).*

C3–4 The method of multipliers applied to CAD of broadband microwave FET amplifiers. *Sun Shiying, Wu Chucheng, Chen Guilu, and Chen Jian (China).*

SESSION A7—RADAR IDENTIFICATION

A7–1 Advances on radar target classification. *Ke Youan (China) and Enzo Dalle Mese (Italy).*

A7–2 A two-dimensional deconvolution algorithm for target classification and recognition with nonsinusoidal signals. *Malek G.M. Hussain and Essmat Y. Masoud (Kuwait).*

A7–4 Target adaptive matched illumination radar, A brief summing up. *Dag T. Gjessing (Norway).*

A7–5 3-D image reconstruction by coherent processing of radar echoes. *G. Corsini and A. Vaccarelli (Italy).*

A7–6 Identification and diagnosis of radar system by using pseudorandom sequence. *Ging Zhayong, Chou Bojin, and Yu Shenje (China).*

A7–7 Using polarization discriminants for target classification and identification. *D. Giuli, M. Gherardelli, and M. Fossi (Italy).*

SESSION B6—DATA PROCESSING

B6–1 Radar data processing. *A. Farina (Italy).*

B6–2 A data processing system of weather radar. *Chin Jinshang, Chen Yaozu, Zhu Liangcheng, Wu Peifu, and Zhang Wenrong (China).*

B6–4 Optimal fuzzy processes for radar data. *Zhuang Zhaowen and Guo Guirong (China).*

B6–5 A digital velocity and acceleration designation system. *Tong Kai and Li Jiliang (China).*

B6–6 Data processing for multiple MPRF airborne PD radars. *Jin Yiwen (China).*

B3–8 Research and application of sea clutter suppression technique for terminal guidance radar of sea defence missile. *Yuan Faxie (China).*

SESSION D1—RECEIVERS

D1–1 Receiving module for solid state phased array radar. *Yin Liansheng, Zhou Gengxiang, Gu Zhongru, and Ma Hengtai (China).*

D1–2 SAW compressive receiver. *Geng Fulu and Xie Chanrong (China).*

D1–3 Marine colour radar displays. *E.R. Ibbetson (U.K.).*

D1–4 A digital controlled multi–target receiver system with wide dynamic range. *Sun Lisheng, Lin Pingping, Huang Wenxin, Liu Peishan, Qi Min, Duan Changgeng, Wang Cuifu, Guo Shiling, and Liu Qiwen (China).*

D1–5 Realization of pulse compression by using BRAC. *Fang Mingyu, Tang Huizhu, and Zhu Lihua (China).*

D2–5 100 kW L–band transmitter for low flying detection radar. *D.P. Gupta (India).*

THREE OUT-OF-THE-ORDINARY HYDRODYNAMICS RESEARCH INVESTIGATIONS UNDERWAY IN JAPAN

Justin H. McCarthy

Three recent Japanese research efforts in hydrodynamics are described and their importance outlined. They deal with magnetohydrodynamics, extraction of wave energy, and surface tension effects.

INTRODUCTION

As a result of visits to 16 ship research establishments in Japan over the past several months, I have selected three out-of-the-ordinary research investigations which may be of general interest to the readers of this publication. Each involves hydrodynamics research using experimental, theoretical, or numerical investigative approaches. Two of the investigations deal with high-risk concepts that ultimately may have shipboard applications; the third investigation bears on assumptions that traditionally have been used in predicting ship resistance from model experiments. I have been repeatedly impressed by the competence, versatility, vigor, and optimism of the individuals conducting these and other research investigations throughout Japan.

The first investigation concerns numerical simulations of flow control about lifting surfaces in seawater using an electromagnetic field. This work is being conducted at the Ship Research Institute in Tokyo. The second project, which will soon enter the sea trials phase, deals with a novel "wave devouring propulsor" under development at Hitachi Zosen's Technical Researcn Laboratory in Osaka. The third research effort, being conducted at Yokohama National University, examines the role of surface tension in the prediction of ship resistance from model tests.

MAGNETOHYDRODYNAMIC (MHD) FLOW CONTROL AND LIFT ENHANCEMENT FOR HYDROFOILS

Since 1985, Munehiko Hinatsu of the Ship Research Institute (SRI) in Mitaka (Tokyo), Japan Ministry of Transport, has been performing pioneering numerical simulations of viscous flows of seawater, a conducting fluid, in the presence of electromagnetic fields. He has considered a number of different one- and two-dimensional boundary valu problems, building on the theoretical and numerical methods developed by Yoshiaki Kodama (1985), his colleague at SRI, for non-MHD flows.

Hinatsu's first paper, coauthored with Kodama (Hinatsu and Kodama, 1986), deals with the magnetohydrodynamics of laminar flow inside ducts and around elliptic cylinders. In this work, confined to low Reynolds number flows, internal flow separation on the wall of a diverging duct is found to be more easily controlled by MHD than external flow separation on the downstream surface of a cylinder. A subsequent paper (Hinatsu, 1987), dealing with the MHD effect in a one-dimensional model of high Reynolds number turbulent channel flow between parallel walls, concludes that a magnetic field has a damping effect on turbulence and can produce flow relaminarization. The most recent, yet to be published, work of Hinatsu deals with MHD flow control and lift

enhancement for hydrofoils at angle of attack. This significant research will be briefly described below.

The fluid mechanics problem being dealt with in Hinatsu's most recent work is the problem of lift and drag degradation when flow separation occurs on a lifting surface at angle of attack. At low values of Reynolds number, laminar flow separation can occur at relatively small values of angle of attack, say 5°. At high values of Reynolds number, significant turbulent flow separation will occur at higher angles of attack, say 20°. Numerous approaches to lifting surface flow control and separation delay have been investigated in the past. These include the use of boundary layer suction, slotted walls, and vortex generators. Hinatsu classifies these methods as "appendage methods" and the use of MHD as a "field method." One candidate shipboard application of MHD might be to rudders whose lift production is degraded at high angles of attack, resulting in less than optimum maneuvering performance during tight turns.

The normalized MHD field equations for conservation of momentum, mass, and electric potential are respectively given by:

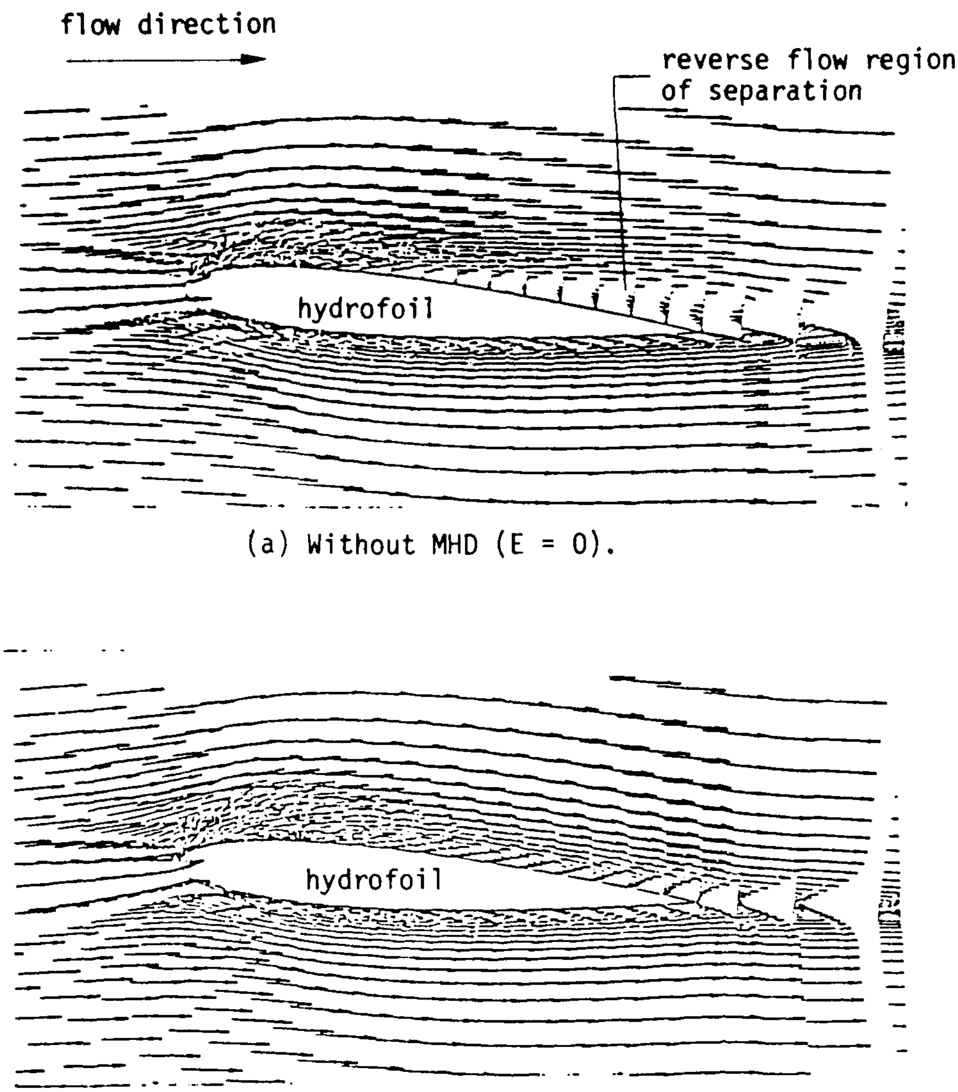
$$\frac{Du}{Dt} = -\nabla p + \frac{1}{R_n}\Delta u + \frac{Ha^2}{R_n}(-\nabla\phi + u \times B) \times B$$

$$\nabla \cdot u = 0$$

$$\Delta \cdot \phi = B(\nabla \times u)$$

Here, u, p, and ϕ, which are to be solved from the equations, and **B** are, respectively, the nondimensional values of velocity, pressure, electric potential, and magnetic field. R_n and Ha are nondimensional numbers depending only on the physical properties of the fluid (density, viscosity, electrical conductivity, and magnetic diffusivity) and the length and velocity scales of the particular boundary value problem being treated. R_n is the Reynolds number, a measure of the ratio of inertial forces to viscous forces, and Ha is the Hartmann number, the square root of a measure of the ratio of electromagnetic forces to viscous forces. Thus, Ha^2/R_n is a measure of the ratio of electromagnetic forces to inertial forces. When $Ha^2/R_n \rightarrow 0$, the field equations reduce to the classical equations of hydrodynamics.

Hinatsu has used an implicit approximate factorization scheme and boundary-fitted coordinates to solve the MHD equations for laminar flow, with $R_n = 10^4$ and Ha = 12.64, about an NACA 0012 symmetrical hydrofoil (wing) section set at a 5° angle of attack. In the absence of an electromagnetic field, laminar separation was predicted to occur on the leeside of the hydrofoil. This is shown in Figure 1, where separation is indicated by reverse flow velocity vectors above the upper surface of the foil downstream of about the 50-percent of chord location. As electric field strength, $E = -\nabla \cdot \phi$, was increased, the region of flow separation was monotonically reduced in length and finally eliminated when E reached a value of about −150, as shown in Figure 1b. As a result, hydrofoil lift coefficient (C_L) increased and drag coefficient (C_D) decreased dramatically when the strength of the electric field was increased, as shown in Table 1. The large increase in lift results from the altered flow (reduced separation) and improved hydrofoil pressure distribution with little contribution to lift directly from the electromagnetic force. The opposite is true for the drag reduction, which is nearly entirely due to an electromagnetic thrust that counteracts the hydrodynamic drag of the hydrofoil.



(a) Without MHD (E = 0).

(b) With MHD (E = -150).

Figure 1. Velocity field about NACA 0012 section at $R_n = 10^4$ and Ha = 12.64; 5^o angle of attack.

Table 1. MHD Effect on NACA 0012 Section Lift and Drag for Conditions of Figure 1

E	C_L	C_D	C_L/C_D
0	0.05	0.025	1.8
-50	0.12	0.021	5.8
-100	0.16	0.017	9.6
-150	0.21	0.013	16.4
-200	0.25	0.008	29.8

Future numerical simulations at SRI will consider the more difficult problem of turbulent flow at higher values of Reynolds number. Practical application of MHD will depend on many factors, not the least of which is the electric power requirements for lift enhancement.

WAVE DEVOURING PROPULSION (WDP)

During the past 5 years, Hiroshi Isshiki, Mitsunori Murakami, and their coworkers at the Hitachi Zosen Technical Research Laboratory in Osaka have been conducting research on a concept that allows wave energy to be converted into a propulsive force when a ship advances normal to the crests of ocean waves. In this concept, depicted in Figure 2, a bow-mounted, spring-loaded hydrofoil, free to passively oscillate about its horizontal axis, generates a periodic lift force having a net thrust component in the direction of ship advance. The cross-flow velocities, which provide an angle of attack and produce foil lift, result from a complex interaction of wave orbital velocities, ship pitch and heave motions, and foil "springiness." When the system is properly tuned, wave energy is converted to ship motions, which drive a foil to produce thrust. Because the presence of the foil tends to damp the motions of the ship, the resistance of the ship in waves is reduced, leading to an apparent additional increase of foil thrust.

While it may appear to be so, the phenomenon does not constitute a perpetual motion machine. Dr. Isshiki has dubbed it "wave devouring propulsion" (Isshiki and Murakami, 1983), a title that brings to mind amusing English word combinations found on jackets and sweatshirts popularly worn throughout Japan. According to a feasibility study reported by Isshiki and Naito (1986), significant speed gains (or power savings) can result from application of the concept as an auxiliary propulsor. The speed of an 80-meter cargo ship was estimated to increase from 7.1 to 12.1 knots during winter operations on the Japan-North America route. The calm water speed was 11.4 knots without a foil fitted. Because the foil

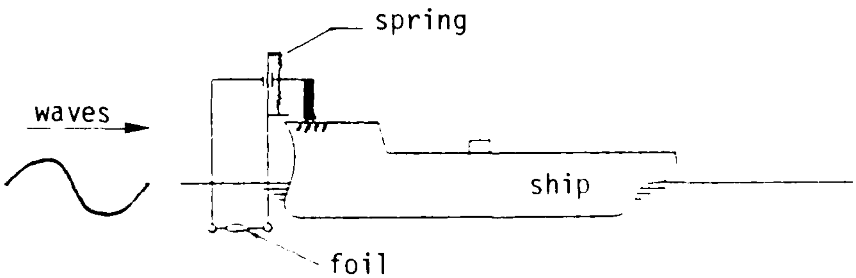


Figure 2. Experimental arrangement.

significantly increases ship resistance in calm water, it would have to be retractible in practical applications. When fuel costs are high, the use of a WDP as an auxiliary power source is no more farfetched than the use of sails, which have been extensively evaluated during the last decade.

According to Isshiki, the WDP concept can be traced back to the beginning of this century. The theoretical foundation for oscillating foil propulsion in waves was given much more recently by Wu (1972) of the California Institute of Technology as were theoretical methods for predicting ship motions when a foil is fitted (e.g., Bessho et al., 1984). Building on these methods, Isshiki and his colleagues have designed and conducted experiments in head seas on a 2-meter ship model to evaluate a wide variety of foil geometries, locations, and spring constants to optimize WDP performance for a range of wave length/ship length (λ/L) ratios between about 0.5 and 2.0.

During an April visit to the Hitachi Zosen Technical Research Laboratory, the amazing performance of the concept was demonstrated to me. Starting from a state of rest, the model began accelerating as soon as the waves reached the model and rapidly moved down the tow tank for values of λ/L around unity, the optimum wave condition for maximum WDP thrust. Figure 3, adapted from Nagahama et al. (1986), shows nondimensionalized computational and experimental data for the hull resistance increase (ΔR) or decrease ($-\Delta R$) in waves without and with the foil fitted. A significant thrust (negative resistance) was realized for wavelengths in the range $0.9 \leqq \lambda/L \leqq 2.0$. The computed results are at least in qualitative agreement with the experimental data.

As a result of the very positive results to date, the Japan Foundation for Shipbuilding Advancement is funding Hitachi Zosen to further evaluate and fine-tune the concept and to carry out sea tests on a WDP

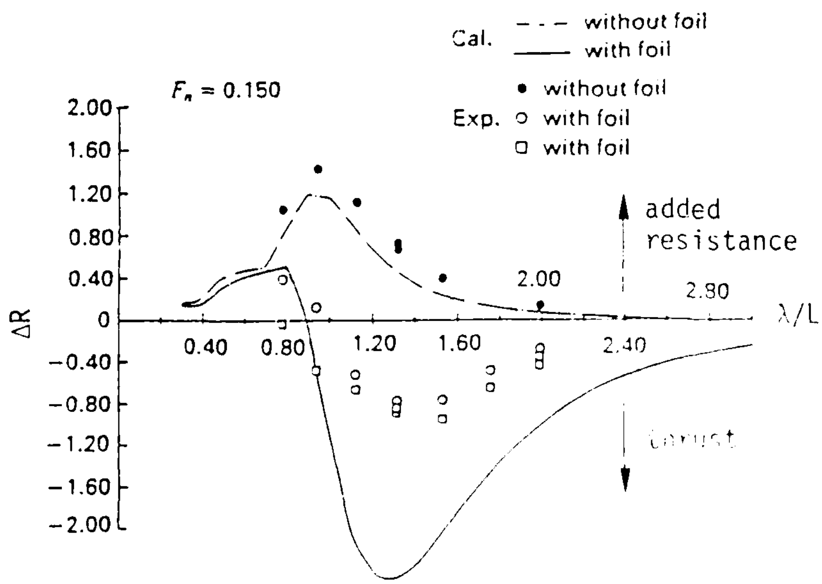
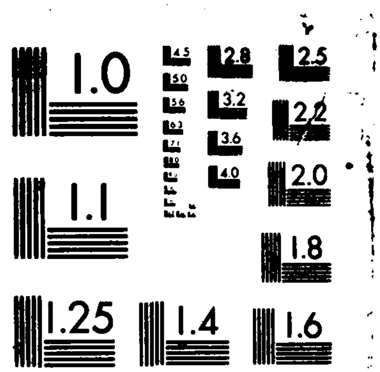


Figure 3. Added resistance in wav... Nagahama et al., 19...

AD-A185 242 ONR FAR EAST SCIENTIFIC BULLETIN VOLUME 12 NUMBER 2 APRIL-JUNE 1987(U) OFFICE OF NAVAL RESEARCH LIAISON OFFICE FAR EAST APO SAN FRANCISCO 96503 2/2

UNCLASSIFIED G B WRIGHT ET AL. JUN 87 F/G 9/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

designed and built for a fishing research/training boat owned by Tohai University. This work was initiated in 1986 and will be completed in 1988 at an estimated cost of ¥52 million (about $370,000). Part of the remaining laboratory effort will be aimed at evaluating WDP performance in nonhead seas. Most of the funding, however, will be for design and hardware fabrication, installation, and subsequent at-sea evaluations of the concept.

EFFECT OF SURFACE TENSION ON SHIP RESISTANCE PREDICTION

It has been commonly believed for many years that surface tension effects on ship model resistance in calm water will be negligibly small provided that the model length is sufficiently large, say longer than about 2 meters. This belief was encouraged in the recent past by the theoretical research of Webster (1966), who computed a very small effect of surface tension on one component of ship resistance, namely the wavemaking resistance, except for very short models.

In fact, traditional methods used by naval architects to extrapolate model resistance experimental data to full-scale conditions totally neglect surface tension effects. For the large commercial and national towing tanks of maritime nations around the globe, which use ship models having lengths of about 6 to 7 meters, the traditional methods are probably valid. For smaller models used in other establishments, however, recent research reported by Professors Hajime Maruo and Mitsuhiro Ikehata of Yokohama National University raises serious questions about the assumed unimportance of surface tension effects on model resistance, even for models as long as 4 meters. From an engineering standpoint, relatively small errors in the estimation of ship resistance, say 5 percent, can lead to seriously degraded or even unacceptable performance of propulsion machinery aboard ships.

In order to understand the importance of these recent findings, it is necessary to digress briefly to explain how naval architects predict ship resistance from measurements of model resistance. Since the century-old classical work of William Froude, the normalized total resistance, C_T, of a ship has been represented as the sum of a normalized viscous resistance, C_V, and a normalized residual resistance, $C_R \equiv C_T - C_V$. On the basis of Froude's research, it is assumed that C_R has the same value at model and full scale for the same values of Froude number ($F_n \equiv V/(gL)^{1/2}$, where V and L are ship speed and length and g is gravity acceleration), a measure of the ratio of inertial to gravity forces. C_R is determined from model measurements of C_T and computed values of C_V, which is assumed to depend only on Reynolds number ($R_n \equiv VL/\nu$, where ν is the kinematic viscosity of water), a measure of the ratio of inertial to viscous forces. The value of C_V is commonly written in the form:

$$C_V = (1 + K)\, C_F$$

where C_F is the normalized frictional resistance of a equivalent flat plate and (1+K) is the "form factor" that is usually assumed to be independent of R_n. This latter assumption is fundamentally incorrect, and the subject of current debate, but will not be addressed here.

In the above breakdown, C_F accounts for the stresses acting tangent to the hull; $C_R + KC_F$ accounts for the pressures acting normal to the hull, C_R and KC_F, respectively, representing wavemaking resistance and form drag.

The value of C_F is computed theoretically and (1+K) is usually determined from the formula:

$$(1 + K) = \frac{C_T}{C_F} - \frac{a}{C_F} F_n^m$$

as the value of C_T/C_F in the limit as $F_n \to 0$, by extrapolation to $F_n = 0$ of measured values of C_T/C_F in the range $0.12 \leqq F_n \leqq 0.20$. The exponent m and the constant a are chosen to give the best data fit. Values of F_n lower than 0.12 are avoided because of the increased risk of laminar flow on the forebody and degraded measurement accuracy at lower towing speeds.

Returning now to the main subject, Maruo and Ikehata (1986) report unique experimental data on the remarkable effect of surface tension on the surface pattern and texture of waves generated by simple wedge-shaped bows and on the measured resistance of 3- and 4-meter model hulls. The data were obtained in towing tank experiments carried out in natural water and in water treated with chemical surfactants that effectively removed the surface tension and thereby better simulated, at model scale, the negligible importance at full scale of surface tension forces relative to inertial and gravity forces.

From their experiments, supported by theoretical wave analyses based on ray theory, it is possible to draw the following conclusions:

1. At model speeds up to about 1.15 m/s, which is considerably higher than the 0.23-m/s critical speed of gravity-capillary waves, surface tension effects increased total model resistance by as much as 8 percent. If form factor were determined from these data at values of F_n near 0.12, errors in (1+K) due to surface tension effects could be as high as 20 percent.

2. A nondimensional scaling parameter, τ, related to Weber number, which characterizes the ratio of inertial effects to surface tension effects, is given by:

$$\tau \equiv V(4gT/\rho)^{-1/4}$$

$$= L^{1/2} \cdot F_n \cdot (4T/\rho g)^{-1/4}$$

where T is the surface tension force per unit length. For the same physical properties of water and the same value of F_n at model and ship scale, it follows that:

$$\tau_S = \lambda^{1/2} \tau_M$$

where $\lambda = L_S/L_M$ is the length scale ratio, ship (s) to model (m).

Thus, there will be a large disparity between the values of τ at model and full scale, and it can be expected that small models will be more prone to surface tension effects than large models, as previously analyzed by Webster (1966).

3. Wave computations based on ray theory indicate that surface tension effects depend not only on τ but also on beam/draft ratio and bow entrance angle. The critical speed required to avoid undesirable surface tension effects on resistance increases with increasing entrance angle. For a 4-meter model with a wedge-shaped bow having a 40° entrance angle, surface tension effects were found to persist at values of F_n greater than 0.18, well within the range of F_n values used in determining form factor. For entrance angles equal to or greater than 60°, the Kelvin wave system ceased to exist at the

bow, the bow being encircled by a turbulent region that might be related to generation of a necklace vortex at the intersection of the free surface and bow.

It is clear from the findings of Maruo and Ikehata that surface tension can seriously affect the determination of low speed resistance and form factor at small to intermediate model scales, particularly in the case of full form ships. Additional data are required for a variety of models to determine the full scope of the problem. Plans are currently being laid to conduct towing tank experiments at Kyushu University and the general topic should be an important item of discussion at the 18th International Towing Tank Conference to be held at Kobe in October of 1987.

REFERENCES

Bessho, M., Y. Kyozuka, and M. Miyazaki. 1984. On the ship motion reduction by anti-pitching fins in head seas (second report). *Journal of the Society of Naval Architects of Japan* 155:84–92.

Hinatsu, M. 1987. k–ε modeling of MHD flow and its simulation of channel flow. *Journal of the Society of Naval Architects of Japan* 161(May): 35–42.

Hinatsu, M., and Y. Kodama. 1986. Numerical simulation of flow controlled by MHD effect – 2-D laminar flow. *Journal of the Kansai Society of Naval Architects of Japan* 201(June): 91–100.

Isshiki, H., and M. Murakami. 1983. A theory of wave devouring propulsion (3rd report) – An experimental verification of thrust generation by a passive-type hydrofoil propulsor. *Journal of the Society of Naval Architects of Japan* 154:125–35.

Isshiki, H., and S. Naito. 1986. An application of wave energy – Thrust generation by a hydrofoil in waves. Symposium on Current Practices in Ocean Engineering, ASME Ocean Engineering Division, New Orleans, La.

Kodama, Y. 1985. Computation of the two-dimensional incompressible Navier-Stokes equations for flow past a circular cylinder using an implicit factored method. *Papers of the Ship Research Institute of Japan* 22(4), July.

Maruo, H., and M. Ikehata. 1986. Some discussions of free surface flow around the bow. In *Proceedings of the 16th Symposium on Naval Hydrodynamics.* Berkeley, Calif., July.

Nagahama, M., M. Murakami, and H. Isshiki. 1986. Effects of a foil attached to a ship in waves. *Hitachi Zosen Technical Report* 47(3&4): 38–43.

Webster, W.C. 1966. *The effect of surface tension on ship wave resistance.* University of California, Berkeley, College of Engineering, Report NA-66-6. Berkeley, Calif.

Wu, T.Y. 1972. Extraction of flow energy by a wing oscillating in waves. *Journal of Ship Research* (March): 66–78.

Justin H. McCarthy is on leave from the David Taylor Naval Ship Research and Development Center, where he was head of the Naval Hydromechanics Division and Technical Manager of the Navy's Propulsor Exploratory Development Program. He will be on assignment with ONRFE/AFOSRFE/AROFE until November 1987. His professional interests include propulsor hydrodynamics, drag reduction, and computational fluid mechanics. Mr. McCarthy is a member of the Advanced Planning Committee of the Society of Naval Architects and Marine Engineers, an Associate Editor of the Journal of Ship Research, and recently served for 6 years as Chairman of the Resistance Committee of the International Towing Tank Conference.

MODERN MATERIALS IN AN ANCIENT INDUSTRY: REPORT ON KAJIMA CORPORATION AND ADVANCED MATERIALS APPLICATIONS

Edward Mark Lenoe

In the United States for several decades now there has been extensive development of various composite materials and associated aerospace structural applications. A great deal of prototype structural development has been achieved, particularly in exotic aerospace applications, commercial aviation, and also sporting equipment. Only a few civil engineers and architects have begun to apply higher performance, more costly materials in various large-scale structures such as bridges, reinforced concrete skyscrapers, and thin shell structures. In Japan, one forward-looking engineering/construction firm, Kajima Corporation, has been using carbon fiber reinforced cement in the construction of multiple-story structures. In this article, the research activities of Kajima Corp. are discussed and some technical details of carbon fiber reinforced cement are provided. Three types of carbon fiber reinforced cement are discussed. Rather remarkable improvements of tensile strain and strength were achieved in continuous fiber and random short fiber reinforced cement and in a lightweight random short fiber reinforced cement with microballoon additions. The latter has already been applied in several major buildings and monumental structures.

INTRODUCTION

Kajima Corporation, Japan's largest construction company, has its own research center, the Kajima Institute of Construction Technology (KICT). KICT was founded in 1949 under the philosophy of Chief Executive Officer Morinosuke Kajima, LL.D. (chairman and president, 1938–75), namely that "constant research and creativity brings about progress and prosperity." For almost 38 years KICT has been involved with research and development (R&D) of construction technology and materials.

KICT is in Chofu, in the suburbs of Tokyo. Presently a large research facility is being built near the institute. This facility will be devoted to research on construction techniques for nuclear facilities and intelligent buildings and plant and equipment investment in the high-tech industries. The total land area of the facility is 43,409 m^2 and the floor area of the buildings is 32,950 m^2. The number of workers in November 1986 was 370 (248 researchers). KICT consists of a Planning and Information Department, General Affairs Department, and four Research Departments.

KICT's roles in Kajima Corporation are:

- R&D of new technology
- Solution of design and construction problems
- Support for technical training of Kajima employees
- Making information on technology and research available to the community

KICT's major research areas include geotechnical engineering, ocean and hydraulics engineering, materials and construction engineering, structural engineering, architectural science and environmental engineering, mechanical engineering, and biotechnology. The institute has a large structural testing laboratory, earthquake simulator, hydraulic laboratory, geotechnical engineering laboratory, materials engineering laboratory, and environmental engineering laboratory. Major activities of KICT include R&D on construction in the ocean, underground, and on soft soils and large high-rise structures.

Typically results of R&D are announced at numerous academic meetings and disclosed to both foreign and domestic research institutions. For example, the Annual Report of KICT, with English abstracts, is sent to 149 universities and research institutions in 40 countries.

TYPICAL RESEARCH ACTIVITIES

R&D of Structures and Foundations

Professor Takuji Kobori (professor emeritus at Kyoto University) was invited to be vice president of Kajima Corporation in 1985. Under his direction the institute has been conducting research on the improvement of earthquake and wind resistance, rationalization of design and construction, and cost reduction. This is one of KICT's specialties. In addition, the research covers a wide range of structural materials, such as reinforced concrete and prestressed concrete and steel. Results are helpful in developing new structures, such as long-span bridges, large caissons, nuclear power plants, LNG tanks, offshore structures, high-rise buildings, and wide-span structures. Particular efforts are devoted to research on a "dynamic intelligent building" that modifies the response characteristics of a building during earthquakes. Regarding soil and rock mechanics and foundation engineering, KICT has numerous developments including "man-made" rock to build larger structures and develop new construction sites.

Oceanographic and Hydraulic Research

KICT has unique testing facilities such as the industry's largest wave basin and wave channel. Research is conducted on ocean structures such as oil storage tanks, ocean platforms, and artificial islands. The facilities enable investigation of the stability of marine structures during all phases of construction. Resulting design and analysis software is generally made available.

Environmental Research

A wide variety of research is conducted in the Environmental Engineering Laboratory, ranging from basic technology to product development on plumbing and sanitation technology, high-voltage air-conditioning systems, clean room technology, acoustic design, noise and vibration control, air conditioning, lighting, etc.

Construction Techniques

Investigations of construction techniques are conducted in the laboratories and on site as well. This includes studies of dam concrete, underwater concreting, and shotcrete. A concrete floor slab-finishing robot developed by Kajima Corp. is used on many construction sites. In foundation engineering, KICT has developed an effective safety management monitoring system for earth retaining walls and a slurry shield system. These both reduce construction time and life cycle costs. In anticipation of continued

expected increases in the use of underground space, KICT has evolved new methods for analysis and monitoring of rock excavations.

Materials Science

The institute is heavily involved in the development of new concrete materials such as underwater concrete, repairing mortar, superplasticized concrete, and waterproofing materials. KICT is particularly active with R&D of cement composite materials using steel and carbon fibers where interest is focused on building applications. In recent years impressive results have been achieved in steel fiber reinforced concrete (SFRC) and carbon fiber reinforced concrete (CFRC). The former is used in the lining of tunnels, staircase treads, and partition walls, which are both fire resistant and sound absorbing. The latter finds use in curtain walls and tiles. Much wider application of these two particular materials is expected in the near future. Let us consider CFRC in detail.

CARBON FIBER REINFORCED CEMENT COMPOSITE

Mechanical Properties

We refer to results of studies on mechanical and physical properties of pitch-based carbon fiber reinforced cement (CFRC) composites developed by Kajima Corp.* Data are presented for unidirectionally aligned continuous fiber reinforcements subjected to tension and for CFRC reinforced with short random carbon fibers. The short fibers were 10 mm long, with a 14.5-micron diameter, mixed in four types of matrixes: two with cement paste and two with mortars with a maximum volume content of 4.5 percent. Effects of autoclave curing were examined.

An interesting facet of this work was the efficient evaluation, coupled with rapid utilization of the potential of this type of material. Reasonable explanations and approximate theories were developed to explain the observations. In spite of some anomalous results, the efforts were extremely focused and quickly transitioned to productive field utilization. While the scale of research was relatively small in contrast to typical materials science research, the results were rapidly transitioned to several major construction projects.

Materials and Specimen Preparation

The properties of the pitch-based carbon fiber used in the experiments are as follows:

Fiber diameter	14.5×10^{-3} mm
Specific gravity	1.63
Tensile strength	7,800 kgf/cm^2
Modulus of elasticity . .	3.8×10^5 kgf/cm^2
Elongation	2.1%

Continuously Reinforced CFRC. The parameters for continuous fibers are:

*Akihama, S., T. Suenaga, and T. Banno. 1984. *Mechanical properties of carbon fiber reinforced cement composite and the application to large domes*. Kajima Institute of Construction Technology, KICT Report no. 53. Tokyo, Japan, July.

Fiber volume content	0 - 5%
Fiber orientation	Continuous fibers are aligned in the direction of the stress
Cement	Ultra high-early-strength Portland cement
Aggregate	None
Admixture	High-performance, water-reducing admixture; Methyl cellulose
Mix proportion	See below
Fabrication	Hand lay-up method
Curing	20 °C, 65 - 80% RH
Age of test	7 days

The mix proportions of cement matrices are as follows:

Water/Cement Ratio (%)	Weight (kg/cm³) Cement	Water	Admixture
31.0	1,586	463	28.5[a]
53.4	1,171	625	11.7[b]

[a]High-performance, water-reducing admixture.
[b]Methyl cellulose.

Methyl cellulose and hydroxypropyl methyl cellulose polymers are commercial products suitable for a broad range of end use applications. These polymers are prepared by the reaction of methyl chloride and propylene oxide with cellulose (wood pulp or cotton linters) in the presence of sodium hydroxide. For ceramic applications these polymers have been used as binders for glaze and in extrusion and injection molding. Methyl cellulose polymers reduce surface tension and promote wetting of powders, usually resulting in polymer coating around each particle.

A rectangular tensile specimen with end tabs, as shown in Figure 1a, was used for unidirectionally reinforced CFRC. The specimens were prepared using cement paste. Continuous fiber sheets of about 1,000 filaments per centimeter width were manually laid, alternating layers of fiber and cement paste between the aligned continuous pitch fibers. Tensile tests were conducted in a 10-ton-capacity Instron testing machine at cross-head speeds of 0.5 mm/min, and strain measurements were made using resistance wire gauges of 60 mm gauge length. For short random fiber reinforced CFRC the "dogbone" specimen shown in Figure 1b was used.

Short Random Fiber CFRC. The properties of the silica powder aggregate for CFRC using short random fibers (10 mm long) with a 690 aspect ratio (fiber length ÷ fiber diameter) are as follows:

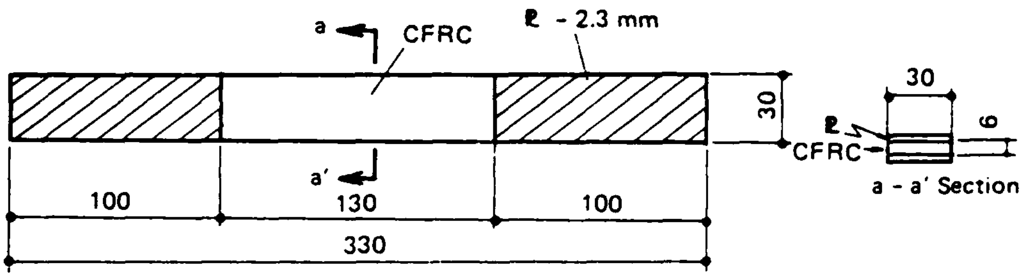
Chemical components (%)

SiO_2	95.0
Al_2O_3	2.17
Fe_2O_3	1.17

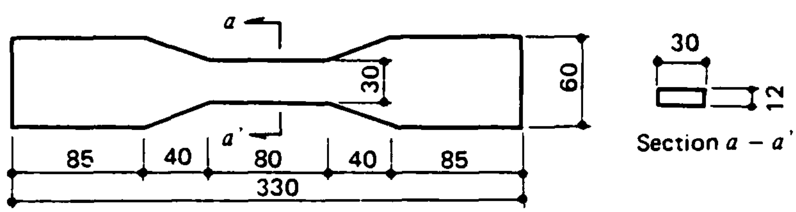
Physical properties

Specific density	2.70
Specific surface	3,360 cm²/g

Four matrix types were used (Table 1). Fiber volume fraction varied up to 4.5 percent. Pitch fibers were the same as used in continuously reinforced specimens.



(a) Unidirectionally reinforced CFRC.



(b) Short random fiber reinforced CFRC.

Figure 1. Shapes and dimensions of test specimens for direct tensile strength.

Table 1. Mix Proportions for Cement Matrices - Short Random Fiber CFRC

Water/ Cement Ratio (%)	Aggregate/ Cement Ratio	Weight (kg/m^3) of--			
		Water	Cement	Fine Aggregate	Admixture
42.0	--	544	1,294	--	13.0[a]
47.3	0.25	512	1,082	274	10.8[a]
52.7	0.50	488	926	460	9.3[a]
29.8	--	467	1,568	--	29.0[b]

[a]Methyl cellulose.
[b]Water-reducing admixture with high performance.

The various matrix combinations were mixed for about 6 minutes in a 10-liter-capacity mixer. Actually, for all material types a number of mechanical tests, including tension, compression, and several types of bending tests, were conducted. All specimens were demolded 24 hours after preparation and cured in air at 20 °C with 65-percent relative humidity (RH). Mechanical testing was conducted after 7 days of aging under these conditions. In this article we concentrate on tensile properties since they illustrate the improvements achieved via additions of carbon fiber.

Lightweight CFRC Reinforced Wi h Short Random Fibers. The previous CFRC used either cement paste or silica sand mortar as matrices. In this phase of the project, CFRC with microballoon mortar matrix was evaluated. The target value specific gravity and volume fractions were 1.0 to 1.3 and 2 to 4 percent, respectively. Special rapid hardening Portland cement was used. The properties of the microballoon aggregate are:

Chemical components (%)

SiO_2	67.0
Al_2O_3	14.0
Others	19.0

Physical properties

Specific gravity	1.00
Particle size	0-150 μm

Table 2 lists the mix proportions for the cement matrices. Figure 2 illustrates the size distribution of particles, which was an important facet of the material preparation. This material was also prepared in a simple 10-liter-capacity mixer.

Curing and aging of the lightweight CFRC was done in two ways:

1. Curing in air: 24 hours after molding the specimens were demolded and left in a conditioned room at 20 °C and 65-percent RH. Tests were conducted after 7 days.

2. Autoclaving: 24 hours after molding the specimens were demolded and left in a conditioned room at 20 °C and 65-percent RH for 1 day. Then they were autoclaved with a temperature increase speed of 60 °C/h and a maximum temperature of 180 °C (10 atm) for 5 hours (for details see Figure 3). After autoclaving, the specimens were left again in a conditioned room at 20 °C and 65-percent RH. Tension, compression, and bending tests were performed after 7 days (the same as for curing in air).

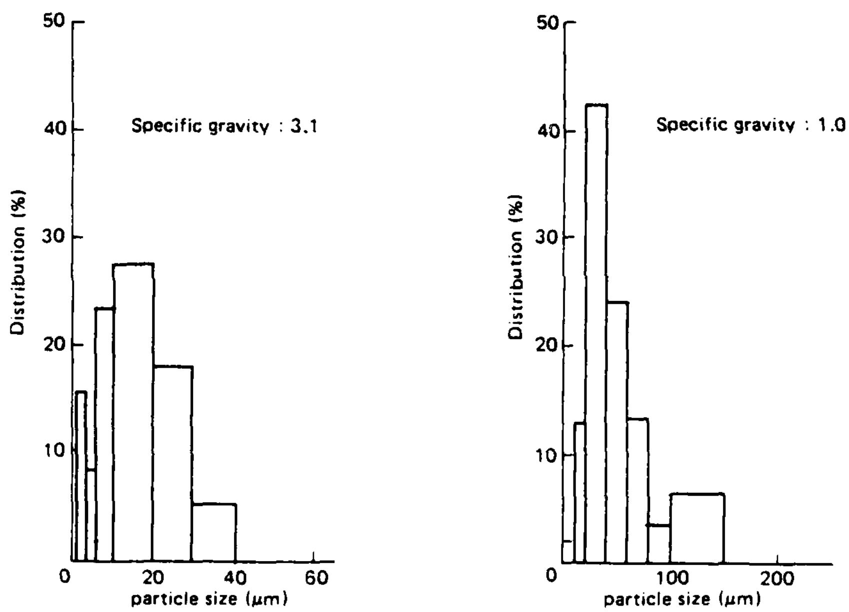
Observed Tensile Behavior

Continuously Reinforced CFRC. The response of continuous fiber reinforced CFRC is illustrated in Figures 4 and 5. Referring to the typical data (Figure 4a), it is seen that the addition of rather small volume percents of reinforcement substantially enhances the total strain capability of the cement. For example, by adding pitch-based carbon fiber with a 3- to 5-percent volume fraction, an extremely "ductile" and tough composite building material with strengths ranging from 80 up to 140 kgf/cm^2 and strains of about 11,000 x 10^{-6} can be produced. KICT researchers have developed simple algebraic expressions to represent various portions of the idealized stress-strain curve illustrated in Figure 4b. They have also derived equations to fit the observed crack spacing versus volume fraction responses shown schematically in Figure 5.

Table 2. Mix Proportions for Cement Matrices - Lightweight CFRC Reinforced With Short Random Fibers

Water/Cement Ratio (%)	Aggregate/Cement Ratio	Weight (kg/m^3) of--			
		Water	Cement	Fine Aggregate	Admixture[a]
62	0.24	508	821	195	8.2
113	0.72	504	446	318	4.5

[a]Methyl cellulose.



a. Special harc'-ning Portland cement

b. Micro-balloon

Figure 2. Particle size distribution.

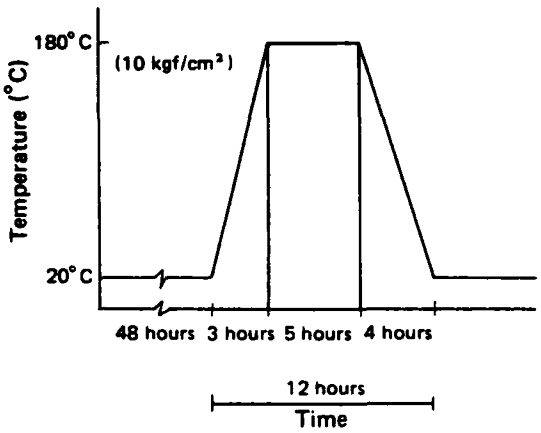


Figure 3. Time-temperature curve of autoclaving.

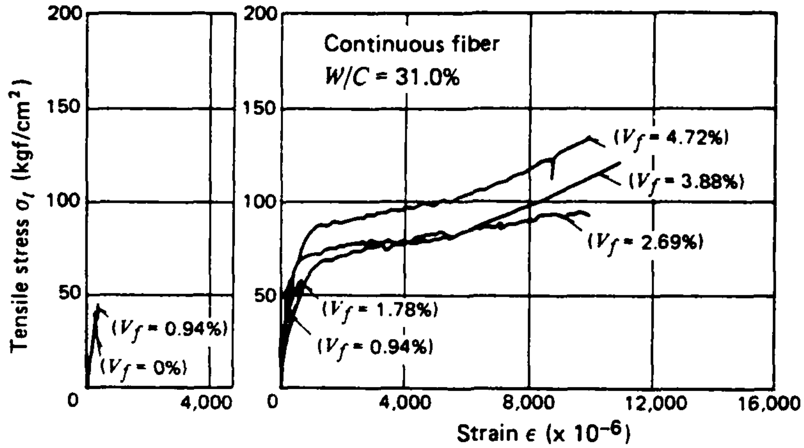
Short Random Fiber CFRC. Regarding the short random fiber reinforced CFRC, it was anticipated that the composite material density would be linearly reduced with increased carbon fiber volume fraction. However, the density reduction was larger than anticipated. This was especially the case for the matrix that contained methyl cellulose (MC) as an admixture. It was conjectured that air voids introduced during mixing contributed to weight reduction. Typical tensile behavior of short random fiber reinforced CFRC is shown in Figure 6. It is se-- that tensile strength and strain to failure are also improved substantially by the addition of carbon fiber. A higher water cement ratio (Figure 6a) leads to a material with larger elongation capability, while a lower water cement ratio (Figure 6b) produces higher strength composites. Observations of failure modes indicated little fiber pullout; most of the fibers failed in direct tensile fracture, suggesting fairly good fiber/matrix interface bond strength.

It was observed that the tensile strength of this type of CFRC increased almost linearly with increasing fiber volume fraction. The maximum increase in tensile strength per 1 percent volume fraction of carbon fiber was 21.8 kgf/cm^2 while the minimum increase was 6.7 kgf/cm^2. This was rather low compared to the continuous fiber reinforced specimens. Interestingly, the compressive strength was **decreased** almost linearly as fiber volume fraction was increased. However, the measured strain at maximum compressive stress was not markedly affected by fiber additions.

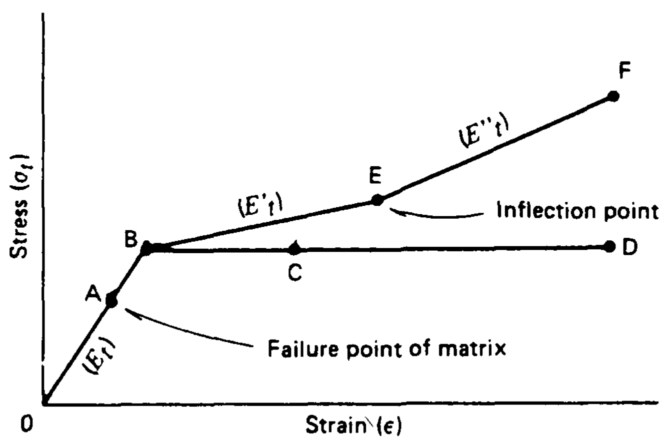
Lightweight CFRC Reinforced With Short Random Fibers. The tensile response of lightweight CFRC reinforced with short random fibers is shown in Figure 7. In this instance, the light weight was achieved via additions of microballoons as aggregate. Particle sizes were chosen as close as possible to the diameter of the carbon fiber to enhance interfacial bond strength. It was found that the target values of density (e.g., $\rho = 1.0$ to 1.3) could be achieved several ways. For instance, with an aggregate/cement ratio (S/C) of 0.24, a water/cement (W/C) ratio of 62 percent, and a fiber volume fraction of $V_f = 1.7$ to 4 percent, the air-dried specific gravity was 1.2 to 1.35.

When S/C = 0.71, W/C = 113 percent, and $V_f = 2$ to 4 percent, then ρ was about 1.0. It was observed that tensile strength for all matrices investigated increased with increased fiber fraction. Tensile strengths ranged from 44 to 80 kgf/cm^2 and strains ranged from about 4,000 to 9,000 x 10^{-6}. Regarding compressive response, there were slight changes for fiber additions ranging up to 4 percent. However, both compressive strength and modulus were larger for the

autoclave-cured materials. While the compressive strain at maximum compresssive stress was slightly higher in both air- and autoclave-cured composites compared to the matrix strains achieved, no clear relationship between maximum strain and fiber volume fraction was found.



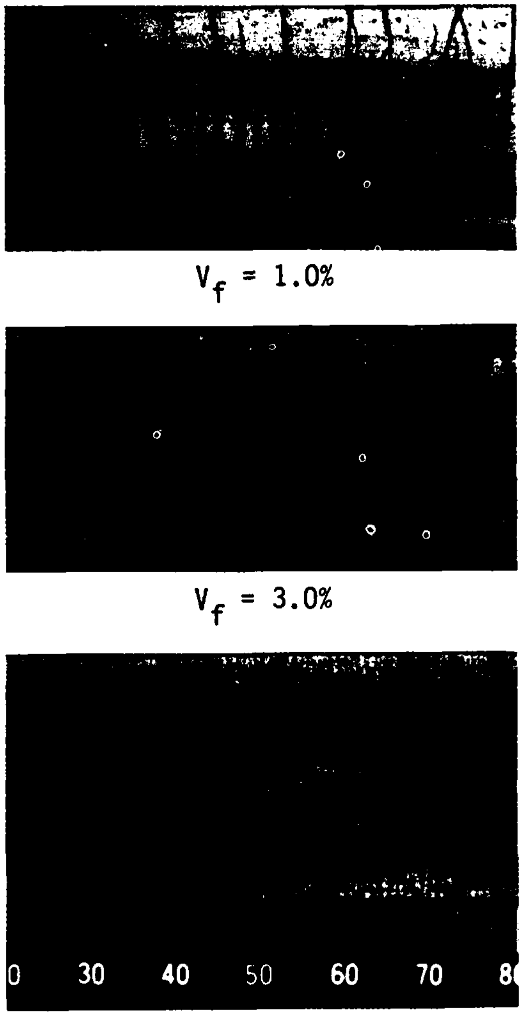
(a) Typical data.



(b) Idealized stress-strain curve.

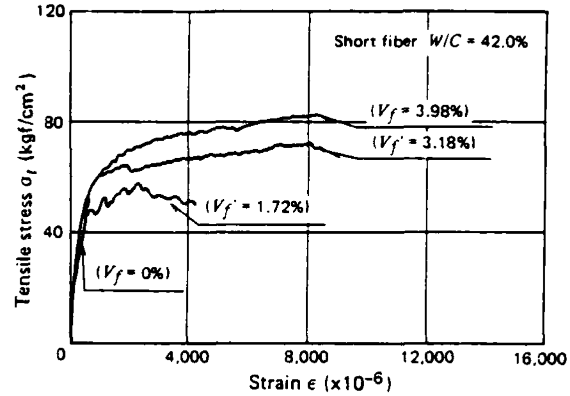
Figure 4. Tensile behavior - continuous fiber reinforced CFRC.

W/C = 53.4%

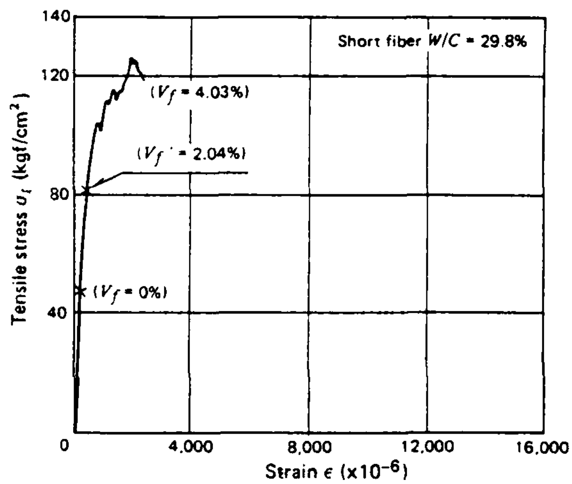


V_f = 5.0%

Figure 5. Crack patterns in tensile test.



(a) Tensile stress-strain curves - high water cement ratio.

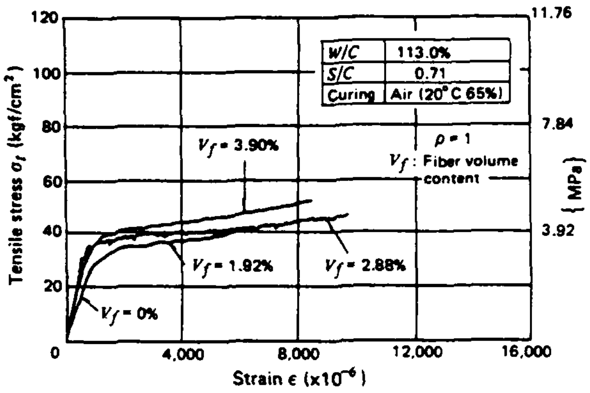


(b) Tensile stress-strain curves - low water cement ratio.

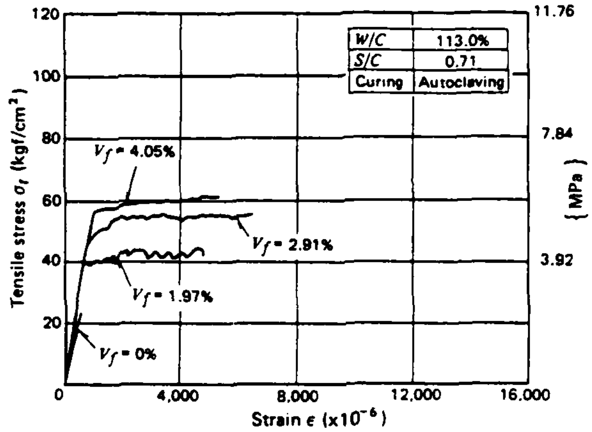
Figure 6. Typical tensile behavior - short random fiber reinforced CFRC.

CONCLUSIONS

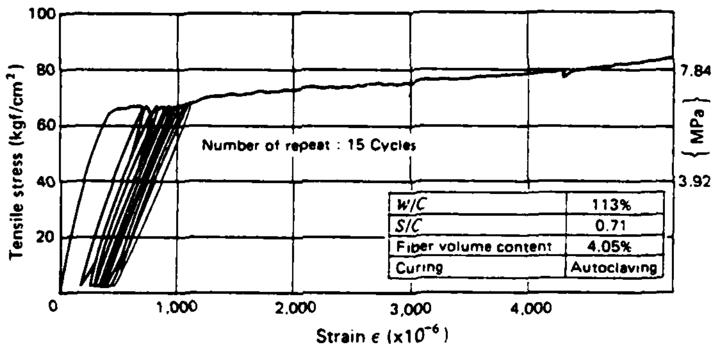
An interesting class of carbon fiber reinforced cement was developed and subsequently applied to civil construction by Kajima Corporation. In the Roppongi area of Tokyo several high-rise structures were constructed using these materials for curtain walls. The new 37-story Akasaka Roppongi Redevelopment High Rise Office Building (called ARK) was constructed with this carbon fiber reinforced concrete, which is about three to four times stronger than conventional curtain wall material. This ARK tower building used 170 tons of pitch-based carbon fiber. Use of the CFRC, which resulted in a 20-percent saving of steel reinforcing rods, simplified the construction process and improved space utilization.



(a) Tensile stress-strain curves for CFRC - air cured.



(b) Tensile stress-strain curves for CFRC - autoclaved.



(c) Stress-strain curve for CFRC with cyclic tensile loading - autoclaved.

Figure 7. Tensile behavior - lightweight short random fiber CFRC.

Another practical use of CFRC is for monumental dome structures. Kajima also constructed the Al Shaheed monument in Iraq, which consists of two domes of similar shape with a height of 40 meters and a bottom diameter of 45 meters. These domes are covered with Turkish blue porcelain tiles. The original plan was to cover the domes with 20-cm^2 copper plates attached to a galvanized steel skeleton support structure. Then cost and durability considerations resulted in choosing tile panels for cladding. This required panels with weights less than 60 kg/cm^2 and with exceptional environmental durability. As a consequence, high-pressure, steam-cured, lightweight CFRC panels were chosen and found satisfactory. It is obvious that applications such as those just cited could lead to considerable expansion of the market for pitch-based carbon fibers.

Let's conclude with some vital statistics on growth patterns in carbon-fiber markets. PAN-based carbon fibers were introduced in the United States in 1961. In 1973 about 140,000 pounds of carbon fiber were used in the U.S., and by 1985 the market had grown to 3.5 million pounds. The cost of such fibers dropped from an average of \$85/lb to \$32/lb in the same time frame. Major U.S. markets for carbon fiber pre-pregs in 1985 were: military aircraft (1 million pounds), sporting goods (660,000 pounds), missiles and space applications (510,000 pounds), commercial transport (420,000 pounds), helicopters (310,000 pounds), and aircraft engines and business aircraft (80,000 pounds each). The total market value of these carbon-fiber-based pre-pregs was about \$150 million.

Estimates of carbon-fiber capacity in 1984 were made by the U.S. Department of Commerce (DOC), and these results are listed in Table 3. Note that of the total capacity of about 18 million pounds, 42 percent is in Japan, 32 percent is U.S. based, and 26 percent is in four other countries. As far as the relatively high priced carbon fibers, capacity far exceeds current demands, but the market is expected to grow. DOC sources quote Toray Industry estimates that world consumption of carbon fibers will be about 7.7 million pounds by 1987; however, a DOC survey completed in 1985 estimates that U.S. consumption alone will be 4.5 million pounds in 1987 and 8.4 million by 1990.

Note that Table 3 lists only two sources of pitch-based fiber. Otani and Oya (1986)* recently provided a status report on pitch-based carbon fiber in Japan. Last summer they reported that the world demand of carbon fiber in 1985 was estimated to have been over 7 million pounds of which 80 to 90 percent was PAN-based carbon fiber. Japan supplied a major portion of the market, along with a domestic demand of about 1.5 million pounds. Kureha Chemical Industries Company continues to be the major commercial supplier of pitch fiber at a scale of about 400 tons/yr. However, there are many new entrants as potential suppliers from iron, oil refinery, and chemical industries. The number of competitors is estimated to be at least 23 and possibly 30 companies trying to commercialize pitch fibers. Obviously, large-scale structures will play a vital role in the future market expansion of pitch-based fibers.

*Otani, S., and A. Oya. 1986. Status report on pitch-based carbon fiber in Japan. In *Proceedings of the Third Japan-U.S. Conference on Composite Materials*. Ed. K. Kawata, S. Umekawa, and A. Kobayashi. Tokyo: Kokon Shoin Co., Ltd.

Table 3. Carbon-Fiber Production Capacity by Country and Firm, 1984

Country	Producer	Precursor	Capacity[a] (lb/yr)
United States	Union Carbide	PAN	800,000
	Union Carbide	Pitch	1,000,000
	Hercules	PAN	1,300,000
	Celanese	PAN	600,000
	Hitco	PAN	250,000
	Great Lakes Carbon	PAN	400,000
	Stackpole	PAN	250,000
	Hysol-Grafil	PAN	330,000 (700,000)
	Polycarbon	Pitch, rayon	110,000
	Avco	PAN	110,000
Japan	Toray Industries	PAN	2,780,000
	Toho Rayon	PAN	2,250,000
	Asahi Nippon Carbon Fiber	PAN	400,000
	Nippon Carbon	Rayon	130,000
	Mitsubishi Rayon	PAN	260,000 (700,000)
	Sumika-Hercules	PAN	(800,000)
	Kureha Chemical	Pitch	300,000
United Kingdom	Courtaulds	PAN	770,000
	R.K. Textiles	PAN	450,000
France	Soficar	PAN	660,000 (700,000)
West Germany	Sigri	PAN	150,000
	Enka	PAN	660,000 (1,100,000)
Israel	Afikim	PAN	200,000
Total	28 Producers		18,160,000

[a]Capacities in parentheses were expected to come onstream in 1985 and 1986, and they are included in the total. Capacity may also be expanded at Hercules and Stackpole during the next few years.
Source: U.S. Dept. of Commerce.

Kajima's carbon fiber reinforced cement made by adding 3- to 10-mm fibers to special cement mortar, with 2- to 4-percent fibers uniformly distributed throughout, is a unique construction material. It has one-half the specific gravity of ordinary concrete. This produces structural members with two to five times the strength, one-half to one-third the cross section, and one-fourth to one-tenth the weight of ordinary structural concrete. As used in the 37-story ARK towers, CFRC curtain walls achieved a 60-percent reduction in wall weight and a 12-percent reduction in seismic load. Construction time was shortened, and gap-free waterproof joints were achieved.

CFRC is as flexible as timber, will hold ordinary nails, and can be planed and sawed. In addition to high strength, durability, and light weight, the material has excellent insulating properties. There are great expectations of an expanded utilization of this highly utilitarian construction material.

Edward Mark Lenoe is on leave from the Army Materials and Mechanics Research Center and will be on assignment with ONRFE/AFOSRFE/AROFE for 2 years, having joined the staff in October 1985. Previously he managed the AMMRC Reliability Mechanics and Standardization Division, served as operating agent for the International Energy Agency implementing agreements on high temperature ceramics for heat engine applications, and also managed numerous major contracts. His initial studies for ONR will be devoted to structural ceramics.

INTERNATIONAL CONFERENCE ON LASER ADVANCED MATERIALS PROCESSING

Thomas W. Eagar

At the International Conference on Laser Advanced Materials Processing, new applications in laser processing were presented. The most promising applications are in heat treatment, coating, and surface alloys. This article presents information on such developments as a 3-kW carbon monoxide laser operating in the 5.1- to 5.8-micrometer wavelength range, transverse flow carbon dioxide lasers, and laser cutting of polymeric materials.

INTRODUCTION

An International Conference on Laser Advanced Materials Processing was held in Osaka, Japan, on 21-23 May 1987. The conference was sponsored by nine professional societies from around the world but was organized primarily by the Welding Research Institute at Osaka University under the direction of Professor Y. Arata. There were 92 papers scheduled for presentation distributed by country as follows:

Japan	32
United States	11
France; People's Republic of China	9 each
Italy	8
U.K.; FRG; U.S.S.R.	5 each
Canada	3
Korea	2
Netherlands; Denmark; India	1 each

Unfortunately, four of the papers from the U.S.S.R. were not presented. There were also 17 poster session papers. About 310 people attended the conference.

The topical areas of the conference were fundamentals, joining, equipment and facilities, surface modification, cutting, and new applications. By far the largest group of papers dealt with surface modification, which included over one-third of all the presentations. This is consistent with the growing consensus that new applications in laser processing are most promising in heat treatment, coating, and surface alloying.

SPECIFIC DEVELOPMENTS

Researchers from Ishikawajima-Harima Industries of Chiba, Japan, presented work on a 3-kW carbon monoxide laser operating in the 5.1- to 5.8-micrometer wavelength range. Efficiencies of 15 percent using lasing gases cooled to 180 K were achieved. No specific application of this new laser is planned other than studying the effect of this new wavelength band on materials processing operations. The laser has been operated for up to 6 hours continuously with only a 10-percent decrease in power output due to decomposition of carbon monoxide to carbon dioxide and oxygen.

A professor from the Laser Institute of Huazhong University of Science and Technology in Wuhan, Hubei, China, described development of 2-, 5-, and 10-kW transverse flow carbon dioxide lasers. It is claimed that these new systems have a more flexible range of operating conditions than the older AVCO HPL laser. In order to conserve helium, systems operating with argon at up to 3 kW were developed with reported efficiencies of 16 percent. Both aerodynamic and coated GaAs windows have

been developed. It was reported that GaAs windows of 50 mm diameter could transmit a 10-kW beam without damage. The professor indicated that these lasers are being offered for sale. The prices are $80,000 for the 2-kW unit and $150,000 for the 5-kW unit (the 10-kW unit consists of two 5-kW units operating in tandem). The 50-mm GaAs windows are priced at $800. These prices appear to be extremely competitive and indicate the strong desire of the Chinese to generate foreign capital.

Other laser presentations from China included LCVD of Ni and $NiSi_2$ films on polysilicon using a CO_2 laser by the Shanghai Institute of Metallurgy and several papers on Nd-glass pulsed lasers from the Huazhong University of Science and Technology. One American faculty member reported that the Chinese are establishing a $145 million educational program a portion of which is devoted to improve laser technology.

In his keynote presentation, Professor Y. Arata of Osaka University presented films of oscillatory flow within an aluminum laser cavity by following tungsten particles with high speed x-radiography. Flows of up to 1 m/s were reported.

In his invited lecture, Dr. R. Bakish noted that there are over 9,000 lasers of greater than 50 watts in the United States; 300 of these are greater than 1 kW and 30 are greater than 5 kW. This compares with 1,200 electron beam machines, most of which vary from 2 to 60 kW. Although 96 percent of the electron beams are used for welding, the bulk of the lasers are used for cutting and heat treatment.

In the third keynote presentation, Mr. M. Contre of France reported that the Central Electricity Generating Board in the United Kingdom has developed a laser-based sensor for unmanned monitoring of corrosion scale thickness in nuclear power plants. The sensor makes use of the high absorptivity of the oxide scale, easily melting the scale while not damaging the more reflective metal.

The Mitsubishi Electric Corporation representative, reporting on beam parameters on weld bead shape, indicated that humped bead defects increase with the magnification factor of annular beams. (The magnification factor is the ratio of the outer annulus diameter to the inner diameter.)

In the presentation from Laser Expertise, Ltd. of the United Kingdom, it was reported that laser cutting of polymeric materials could proceed by either vaporization, melt shearing, or chemical degradation. A professor from the University di L'Aquila of Italy reported that the cut edge quality of fiber-reinforced polymer composites depends on the ratio of thermal conductivities of the polymer and the fiber. Graphite-reinforced polymer composites have poor cut edge quality due to the high thermal conductivity of the graphite, which results in fiber disbonding near the cut edge.

The repesentative from the GMI Institute in Flint, Michigan, reported that up to 0.3 percent of the material removed in laser cutting of Kevlar* resulted in polycyclic aromatic hydrocarbons (PAHs). These PAHs are considered to be carcinogens, which may present problems in laser cutting of polymers. The formation of such compounds appears to be similar to soot formation, which occurs in fuel-rich flames.

Professor K. Inoue of Osaka University described a computer simulation model that appears to accurately predict pearlite dissolution and resulting microstructure of a laser-hardened hypo-eutectoid steel.

*Kevlar is a registered trademark of DuPont Co.

Researchers from Lumonics, Inc. of Kanata, Ontario, Canada, showed that hole drilling in polyimide sheets is much more uniform with a 248-nm excimer laser than with either Nd:YAG or Co_2 lasers.

Dr. H. Peebles of Sandia Laboratories surprised most attendees by showing evidence that the plasma above Nd:YAG welded 1100 aluminum alloys does not inhibit beam interaction by scattering by the free electrons. Rather, it is believed that the plasma may be altering the refractive index of the gas immediately above the metal.

Researchers from Kansai University in Japan reported melting studies on solder using Nd:YAG lasers. The ultimate application is expected to be complete soldering of entire circuit boards by shining the laser through holographic plates for multiple spot focussing of the laser on the circui pattern. The hologram has a transmissivity of about 50 percent.

One of the problems of laser surface hardening is the high reflectivity of the metal surfaces. In order to improve absorption, surface coatings are often used. Researchers at the University of Stuttgart have eliminated the need for coatings by inclining the incident laser beam at a direction greater than the Brewster angle. They have shown that uniform heating intensity can be achieved if the proper beam parameters are chosen. They also indicated that this oblique beam technique is now being used commercially in West Germany.

SUMMARY

The general impressions from this conference suggest that much more research is needed to understand laser materials processing. It is clear that many questions remain as to the mechanisms of beam/material interactions. Many of the presentations were empirical studies of the variations created by process parameter changes. One attendee maintained that lack of knowledge of the controlling parameters is a major obstacle to greater use of laser processing. Knowledge is insufficient to transfer data obtained on one laser system to another.

Relatively few of the presentations presented analyses or calculations of the results; hence, it is felt that laser materials processing is still in its infancy. While it is finding increased industrial application, it is clear that only an incomplete science base exists from which to develop better processes. It also appears that more research on laser processing is occurring in Japan and Europe than in the United States.

Thomas W. Eagar, recently a liaison scientist with ONR Far East, is an associate professor of materials engineering at the Massachusetts Institute of Technology. Dr. Eagar's professional interests are broadly in manufacturing processes for metals and ceramics with more specific interest in welding and joining technology.

OPTOELECTRONICS JOINT RESEARCH LABORATORY: A REVIEW OF ACCOMPLISHMENTS

George B. Wright

The Optoelectronics Joint Research Laboratory operated from 1981 to March 31, 1987, and produced many outstanding results, both in basic science and in applications. These results were published in a series of 262 English language papers. Major topical groupings include Bulk Crystal Growth, Maskless Ion Implantation and Fabrication Technology, Epitaxial Growth, and Characterization studies. The present article presents a collected bibliography for the project and an assessment of the research highlights.

INTRODUCTION

On March 16, we were invited for the last time to visit the Optoelectronics Joint Research Laboratory (OJRL) at Kawasaki for a summation of the accomplishments of the Laboratory over its 5-year lifetime. In a previous article* Dr. James L. Merz of the University of California at Santa Barbara, who spent 4 months doing research at OJRL, presented a fine overview of the Laboratory, as well as giving a good perspective of the opto-electronics scene in Japan, in which the contributions of the Laboratory were embedded. He described particularly well the interaction of the industrial participants at the Laboratory. The Directors of OJRL kindly gave me a bibliography and reprints of the English language publications produced by the project, and it is the purpose of this article to give an appreciation of that work. I believe that the English language articles represent rather completely the results of the project.

As described by Dr. Merz, the Laboratory was divided into six closely interacting groups, as shown in Figure 1. The funding for the project, and its division between the Ministry for International Trade and Industry (MITI) and industry, is shown in Figure 2. When the project started, the exchange rate was about ¥250/$1, but although that has since slid to about ¥140/$1, for expenditures in Japan, that effect is invisible. Figure 3 shows the number of technical staff and the (small) supporting staff for the lifetime of the project.

The technical groups represent a well thought out plan for addressing the roadblocks to achieving optoelectronic integrated circuits (OEIC), and it is natural to review the published work under this schema.

BULK CRYSTAL GROWTH

Optoelectronic integrated circuits need large wafers of single crystal material to serve as substrates upon which subsequent high quality crystals can be grown epitaxially. Two major methods of bulk crystal growth are Horizontal Bridgeman (HB) and Czochralski (Cz), named after their originators. Efforts at OJRL to improve bulk crystal growth techniques centered on the latter because it yields cylindrical ingots from which circular disks, or wafers, can be cut. In the Cz method, whose geometry is shown in Figure 4, a melt of the material to be

*Merz, J.L. 1986. The Optoelectronics Joint Research Laboratory: Light shed on cooperative research in Japan. *Scientific Bulletin* 11(4): 1–30.

grown is located at the hottest part of the furnace, and a **seed** crystal is introduced from above into contact with the surface of the melt. As material from the hot melt freezes out onto the seed crystal, the seed is pulled upward, drawing with it the growing crystal ingot. Rotation between seed and melt is introduced to stir the melt for better homogeneity.

In a binary compound such as GaAs, one component, As, is more volatile at the growth temperature, and serious loss of As by evaporation would result if the surface of the melt were not covered by a liquid encapsulant of boric oxide, B_2O_3. Above the encapsulant a high pressure of inert gas is maintained. This growth method is called liquid encapsulated Czochralski (LEC). When the crystal contains exactly equal proportions of Ga and As, it is stoichiometric. Deviations from stoichiometry usually result in the introduction of electrically active defects into the crystal, with dramatic consequences for the electrical conductivity.

In the purest bulk GaAs there are usually residual impurities at a level around 10^{14} cm^{-3}. The dominant impurities are silicon, which is a shallow donor, and carbon, which is a shallow acceptor, so that the material is either n-type or p-type, depending upon which impurity species is in excess. If the C impurity is in excess, it may happen that the material is **semi-insulating**, if there are deep donor levels near the center of the gap in excess of the C concentration. It is known that such deep levels can be introduced by intentional doping with Cr, but this method has lost its popularity, as it sometimes leads to unreliability in device performance. In unintentionally doped material there are other midgap levels that can appear, among which the most famous is called EL2. The microscopic identity of these levels and the growth conditions that cause them to appear have been some of the major topics investigated by the bulk crystal growth group at OJRL.

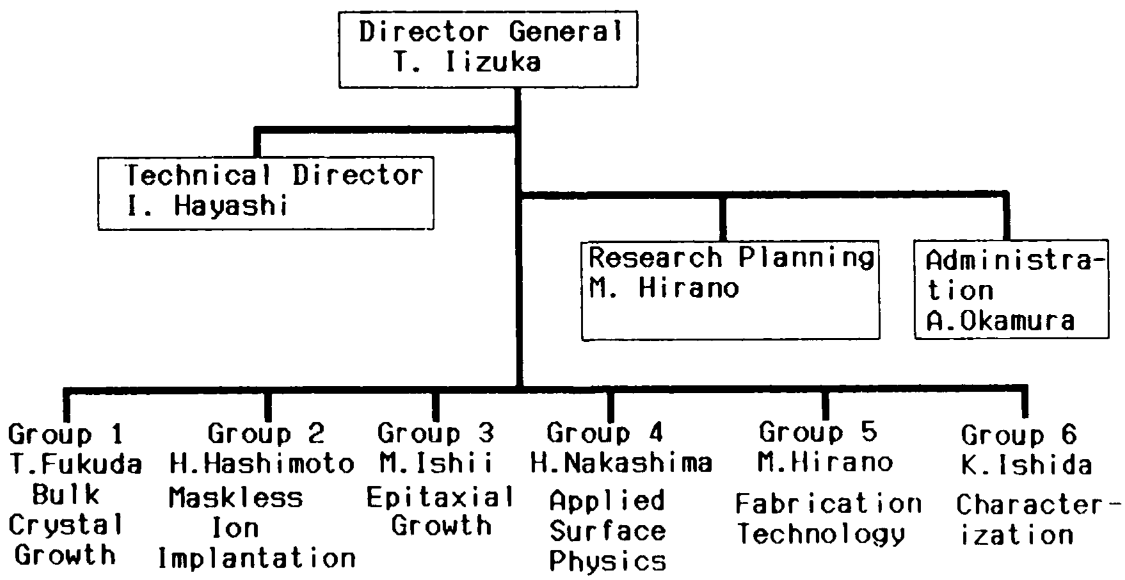


Figure 1. Organization of Optoelectronics Joint Research Laboratory.

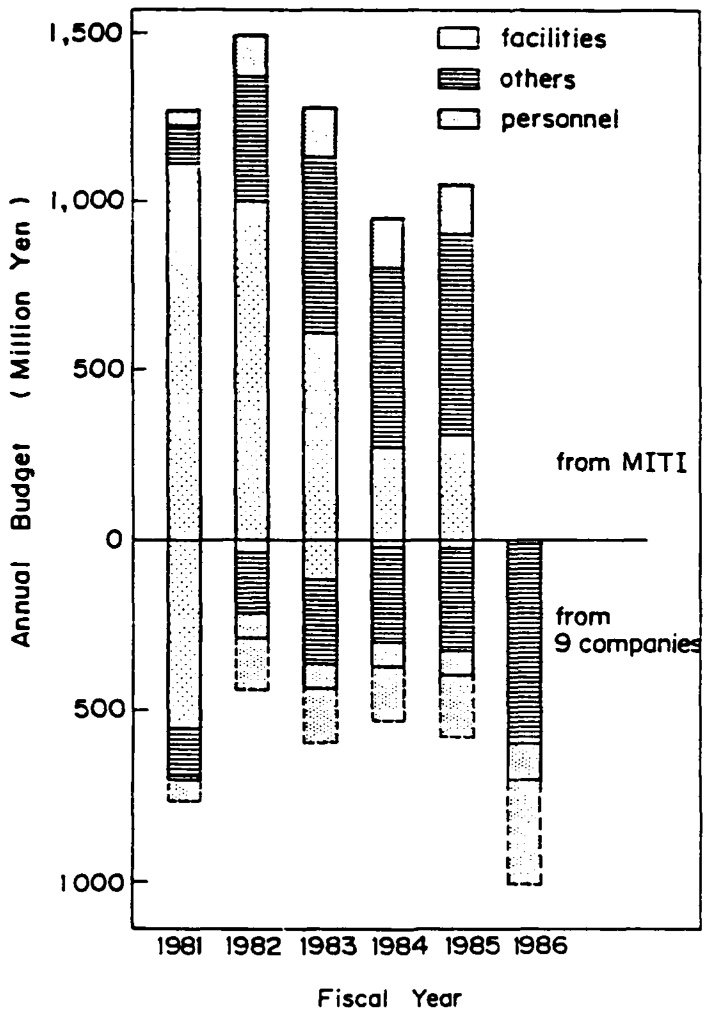


Figure 2. Funding profile of Optoelectronics Joint Research Laboratory.

Another problem of bulk grown GaAs has been the high concentration of dislocations often obtained. Dislocations can be characterized by the etch pit density (EPD) revealed on a surface by a suitable etchant. For GaAs, these numbers could be in the range of 10^5 cm^{-2}, in contrast to Si crystals, which can be grown dislocation free. It was feared that this high dislocation density would simply make it impossible to fabricate high density integrated circuits as had been done for silicon. Furthermore, these dislocations often propagated up through new layers epitaxially grown on the defective substrate, so it was taken as a goal to radically decrease the dislocation density for the bulk crystals, although it was by no means universally agreed that their total elimination was necessary to make integrated circuits feasible.

Use of the wafers for integrated circuits does impose one other very stringent requirement on the wafer:

namely, homogeneity. If threshold voltage for transistors varies across the wafer, the circuit may not work, and the production yield becomes too low to be economically successful. Homogeneity may be measured longitudinally, along the axis of the ingot, and radially, and the results in the two directions may be controlled by different growth factors.

In summary, then, before we review individual contributions to bulk crystal growth, the goals of the project were to improve control of **purity, stoichiometry, homogeneity, dislocation density**, and **deep levels**. Contributions to these goals have been described in 55 English language papers, of which 39 have so far appeared in print. In discussions of these contributions, I will refer to publications by their numbers listed in the Appendix.

In the initial period of the research, an important contribution to in-situ **purification** of the GaAs melt is described in paper 1-1. Purification is obtained by an abrupt decrease in the pressure of the inert gas above the encapsulant, which leads to bubbling in the encapsulant, and apparently to the carrying away of impurities entrained in the bubbles. An order of magnitude reduction of silicon impurity from 5×10^{15} cm^{-3} to 5×10^{14} cm^{-3} was achieved. It was also shown that purity of the melt could reliably be monitored by its electrical resistance, which was certainly of great practical importance in actual operation of the equipment.

The next step forward, reported in paper 1-2, was to improve the dislocation density and spatial homogeneity by **lowering the vertical temperature gradient** during growth. Initially the radial EPD distribution had a W-shaped curve (high at the axis of the ingot and at the surface, lower in-between) and ranged from 2×10^5 cm^{-2} to 5×10^4 cm^{-2}. Reducing the vertical gradient to 50 °C/cm by installation of reflectors in the furnace achieved a U-shaped radial distribution (high only at the surface of the ingot, with a nice large area uniform region inside), with EPD reduced to 10^4 cm^{-2}. This first development demonstrated that temperature gradient was indeed important in causing dislocations, and subsequent decreases would again reduce the EPD.

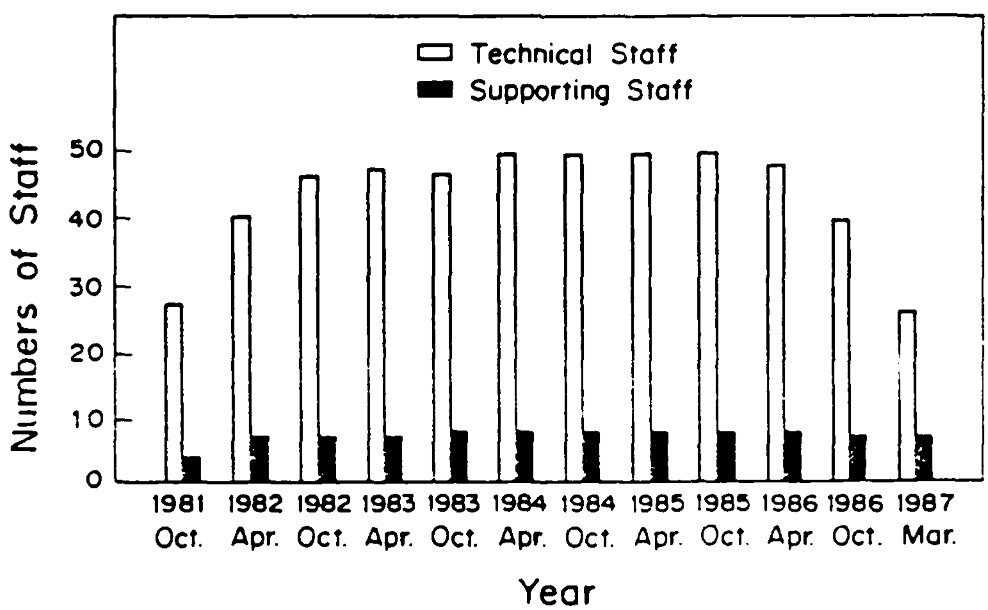


Figure 3. Staffing profile of Optoelectronics Joint Research Laboratory.

Papers 1-5 through 1-8 describe the introduction of an important new variable in bulk crystal growth, the use of a **magnetic field** in conjunction with LEC. The main result was a drastic reduction of temperature **fluctuations** during growth and an increase of the effective viscosity of the melt. Better control with the use of the magnetic field made it possible to more easily demonstrate the effect of other variables, such as pulling rate. A large effect on EL2 concentration was observed.

A convenient framework for thinking about the bulk crystal growth process is provided by the phase diagram, which is shown schematically in Figure 5, where the vertical axis is temperature and the horizontal axis is chemical composition. Two curves are shown: the liquidus and the solidus. Lines of constant temperature are horizontal on this type of diagram. In thermal equilibrium when a liquid and a solid are in equilibrium, the composition of the liquid is found where the temperature line intersects the liquidus, and the composition of the solid is found at the intersection with the solidus. The point where the composition of the liquid and the solid is the same is the congruent point, and for GaAs, the congruent point is thought to be on the As-rich side of the diagram. A change in the temperature from T_1 to T_2 causes a change in the composition of the solid from C_1 to C_2. The diagram is drawn for the case where this causes the composition to change from As-rich to Ga-rich. Now if the crystal is As-rich, there are either Ga-vacancies, As interstitials, or As antisite defects, where As sits on a Ga site. The Ga vacancy and the As antisite defect are thought to be prime candidates for the EL2 center. During ordinary LEC crystal growth, the temperature fluctuates at the growth interface, but when a magnetic field is applied the fluctuations are drastically reduced, and for the appropriate melt composition, the EL2 concentration is also reduced. Temperature fluctuations are suggested on the diagram by dT. The scale of the diagram is expanded greatly beyond the knowledge available about it, so it should be regarded as suggestive only. Paper 1-35 proposes that at the congruent composition, the EL2 defect acts like a dopant with a segregation coefficient of unity; that is, the composition in the melt is the same as that in the solid. Assuming, therefore, that it is important to control the As concentration carefully during growth, papers 1-25 and 1-28 describe apparatus for accomplishing this. Paper 1-25 also describes an important development of an X-ray imaging system for in-situ monitoring of the growth interface during growth.

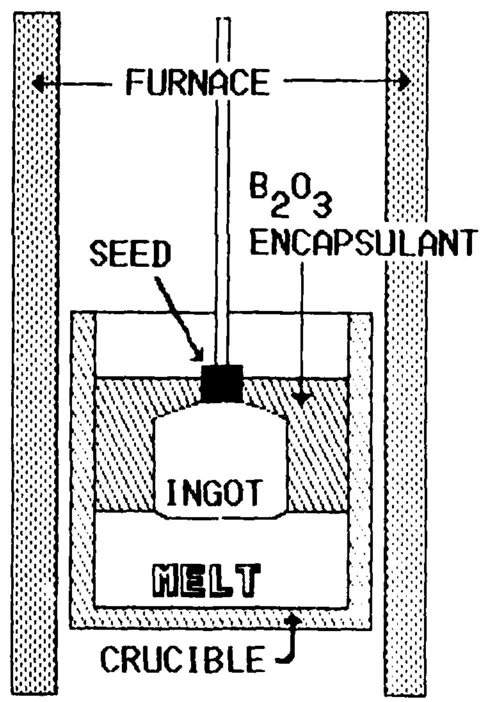


Figure 4. Czochralski crystal growth.

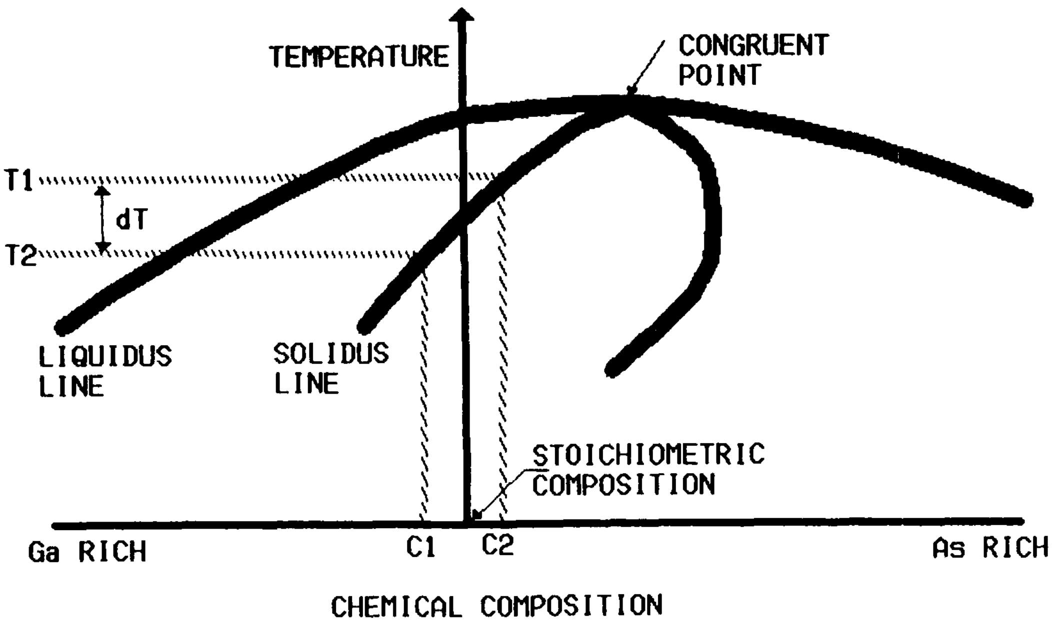


Figure 5. Schematic GaAs phase diagram.

A summary of the accomplishments of the bulk crystal growth group would list:

- Growth of 5-inch-diameter GaAs crystals by computer-automated LEC
- Reductions of dislocations to about $500/cm^2$ by LEC with low temperature gradient and X-ray image monitoring
- Close control of stoichiometry by arsenic-injection LEC
- Stoichiometry evaluation by precision X-ray lattice constant measurement
- Application of magnetic field permitting high-speed pulling
- Contributions to understanding the EL2 defect

Altogether, I would say that the OJRL program on bulk crystal growth of GaAs has produced very many great improvements of crystalline quality during its lifetime. Also, a beginning has been made on growth of bulk InP, which at times in the past had been thought by some to be quite hopeless. There remain learning opportunities, but a very complex set of problems existing when the work began have been rendered far more tractable by the outstanding contributions of this Laboratory.

FOCUSSED ION BEAM IMPLANTATION AND PROCESSING TECHNOLOGY

Up to the present, most semiconductor electronic circuits are fabricated using photolithographic techniques to form the circuits on the wafer. This involves the use of photoresistive materials put down on the

semiconductor surface and elaborate, expensive masks. Avoiding contamination of the surface by this process is always a problem, and its complexity (many steps) is expensive. Some years back, it was thought desirable to replace the photolithography with electron beam lithography (EBL) in order to increase the spatial resolution of the process, but increasing resolution of optical methods, coupled with throughput problems of EBL, have kept the latter from taking over, at least to date. Electron beam lithography also used lithographic resists, whose processing could contaminate the surface.

The motivation for the focussed ion beam implantation research is the hope that circuits could be "written" in a maskless process, possibly in the same vacuum system where other steps in the processing were to take place. New developments in superlattices and superlattice upset by ion implantation have added new dimensions to this aspiration. The papers in group 2 describe the development of focussed ion beam instruments with multi-atomic-species sources suitable for implantation of GaAs with both donor and acceptor impurities. The basic 100-keV system was developed by JEOL in collaboration with OJRL. The liquid metal source allows implantation with Pd, Ni, Si, Be, and B, which can be electronically selected for computer-controlled pattern writing. Computer software was developed providing for drawing circuits with 0.1-micron focussed beams. It was necessary to investigate implantation damage with focussed beams and to look at overgrowth of the implanted layers.

The processing technology papers are listed under group 5 in the Appendix, but the contributions are reviewed together with the focussed ion beam work because of the way the research evolved. The processing research of interest involves the development of nondestructive wafer surface cleaning procedures and dry etching. Originally, the photolithographic etching processes in the electronics industry involved "wet" etching, where the agents were powerful acids. This is a messy, multi-step, expensive process, where a lot of unreliability can be introduced into the resultant product. For some parts of the electronic devices, it is desirable to introduce deep trenches with sharp vertical sidewalls and square corners at the bottom. The depth-to-width ratio is called the aspect ratio, and a high value is often a measure of merit. To achieve this, it is necessary that the etching agent attack the bottom of the trench at a much faster rate than the sidewalls; that is, it must be directionally dependent. This requirement is very difficult for wet etches. In addition, it is desirable that the etchant attack the target and not the mask, if one is used; one wants a high "differential" rate of etching.

It is possible with a beam of ions with high kinetic energy to blast away atoms in the target, using the kinetic energy of the ions to break the bonds chemical bonds of the target. This is called sputtering and is regularly used during Auger electron spectroscopy (AES) to erode away the sample surface as the chemical analysis is performed. As an etching tool for processing, however, it suffers from secondary processes that reduce the resolution and from the introduction of damage into the target. An improvement is to include chemically active ions into the incident beam, with lower kinetic energy. This is called reactive ion beam etching (RIBE) and has high figures of merit for gentle action and high aspect ratios. It is necessary to adjust the chemistry of the beam to that of the target, with the goal of producing volatile products that can be pumped away as the etching proceeds. A compound semiconductor such as GaAs is more complicated than an elemental one such as Si because for GaAs the Ga carriers may not have the same volatility as the As carriers, and

it is possible to drive the surface out of stoichiometry—certainly an undesirable result. If the active beam components are produced in an RF-generated plasma, it is desirable to shield the target from the high energy ions that might produce damage. When this is done, the source is called a shielded plasma, and one type of plasma source that provides this is the electron cyclotron resonance (ECR) source.

RIBE as normally used treats a broad area wafer, using photolithography and masks to define the patterns to be etched. It is the necessity of moving the wafers around to put on the photoresists with attendant exposure of the work to undesirable ambients that is a major flaw in this kind of manufacturing. The enormous expense of "clean rooms" is made necessary in attempting to control and improve the ambient environment in which the wafers are moved. A new glint in everyone's eye is the hope that it might prove possible to do all of the work in a clean ultra-high vacuum (UHV), never exposing the sample to air. This is possibly a major new wave of the future, and we shall see something of the contributions of OJRL to making this possible.

The OJRL work started with the installation of an RIBE system that included, in the same vacuum, analytic instruments such as AES and optical emission spectroscopy. This system and its application are described in papers 5-3, 5-4, and 5-10. Other early papers still study wet etching and laser processing. An important development of radical etching in a Cl_2 plasma was announced in paper 5-14, where ion bombardment damage was completely suppressed. Following this, paper 5-19 describes a surface cleaning apparatus, using hydrogen and chlorine radicals to remove oxygen and carbon surface contaminants resulting from exposure of the sample to air. The apparatus was amusingly termed a "dry cleaning" device. This source of thermal energy radicals also used an ECR plasma and was combined into the same vacuum as the RIBE. This represented an additional step toward all-vacuum processing. The final step involved installation of a focussed ion beam (FIB) device providing 30-keV Ga^+ ions focussed to a fine spot. When the sample was irradiated with Cl_2 or Cl radicals, chemically enhanced sputtering ratios of up to 50 sputtered atoms per incident Ga ion were achieved. This enabled the researchers to etch 6.5-micron-deep grooves, "written" with the ion beam. With this capability, and the addition of crystal growth by MBE, it is no longer necessary to remove the sample to apply photoresists or masks, and the "Factory in a Vacuum" (FIV) has been achieved! In the review of this section, I have omitted mention of many other fine research achievements that were not along the teleological line from RIBE to FIV.

EPITAXIAL CRYSTAL GROWTH

The work of the epitaxial film growth and characterization section was addressed mainly to molecular beam epitaxy (MBE) and metalorganic chemical vapor deposition (MOCVD), looking at how defects, traps, and impurities varied with variation of growth conditions. Characterization methods included deep level transient spectroscopy (DLTS), photoluminescence, photocurrent spatial spectroscopy, and Raman scattering. The growth condition variables investigated for MBE were mainly temperature and V/III flux ratio.

The papers on Raman scattering observation of coupled plasmons and optical phonons gave me a certain personal nostalgic pleasure, as the authors were kind enough to cite the 21-year-old paper where Aram Mooradian and I reported the discovery of the effect made while we were looking for the plasmon scattering predicted by Alan McWhorter. It seems

that the effect is useful for noninvasive characterization of carrier concentration with good spatial resolution. There are, in fact, other electronic Raman scattering phenomena that could also be useful for microscopic utilization, but these seem not to have been applied as yet.

The group also contributed to the development of low-pressure MOCVD and subsequently the development of metalorganic gas sources to replace the Knudsen cells ordinarily used in MBE equipment. The latest refinement is the addition of excimer laser irradiation to enhance doping in the gas-source MBE.

As pointed out by Dr. Merz in his earlier article, the group used the technology developed to demonstrate several improved semiconductor lasers, which served to validate the growth technology. Some of these lasers made use of the impurity-induced disordering of superlattices to achieve index of refraction guided cavities.

A listing of the achievements of the group would include:

- Growth of high quality abrupt interfaces of GaAs/AlGaAs

- Selective growth of GaAs/AlGaAs by low-pressure MOCVD

- Laser-assisted gas source MBE

- Lasers by impurity-induced disordering of superlattices

- LaB_6, a new self-aligned Schottky electrode material

APPLIED SURFACE PHYSICS

The use of the term "surface" must be generalized to include interfaces and superlattices to describe the accomplishments of this group. They looked at phenomena such as the formation of the Au/GaAs interface. Detailed studies showed that the deposited gold film was able to break GaAs bonds even at room temperature, and that the As atoms diffused out through the gold film and segregated at the external surface of the gold. For me this was highly reminiscent of the brilliant work of L. Brillson at Xerox, who also showed how extremely thin "barrier" films of other metals at the interface could inhibit such diffusion.

An interesting new self-aligned Schottky gate material, LaB_6, lanthanum hexaboride, was developed at OJRL and investigated by this group. What is a self-aligned gate? A metal-semiconductor field effect transistor (MESFET) has a metallic gate between the source and drain contacts in the semiconductor. The structure is shown in Figure 6. When the metallic gate is deposited, a Schottky barrier is formed by charge transfer. This barrier to electron flow makes the amount of current that flows nonsymmetric with polarity of the applied voltage, unlike an ohmic contact, which is symmetrical. The barrier is characterized by its height, in electron-volts. The source and drain contacts must be made highly conductive by ion implantation, followed by annealing to "activate" the implanted ions. In addition, the gate electrode must not overlap the source and drain, or undesirable additional capacitance will be introduced, which degrades the high frequency performance of the device. A clever solution is to choose a gate material that will block the ions during implantation, so that the source and drain regions are "self-aligned" during the implantation. But the gate material must be able to withstand the subsequent high temperature annealing necessary to activate the source and drain, and it must not interact chemically with the semiconductor. Lanthanum hexaboride has been demonstrated by OJRL to be a very promising material for self-aligned Schottky gates on GaAs. It is a cubic material with a thermal expansion coefficient of $5.6 \times 10^{-6}/°C$,

compared to 5.7 x 10^{-6}/°C for GaAs. This close match prevents the material from being torn off by differential expansion during processing. The resistivity is only 8.9 x 10^{-6} ohm-cm, so it is a good metal, and the melting point is 2,715 °C, compared to 1,238 °C for GaAs. Research at OJRL showed that the material did not interact with GaAs during processing up to 850 °C and has a barrier height of 0.773 eV. All of these characteristics make it a very promising candidate for use in practical integrated circuits.

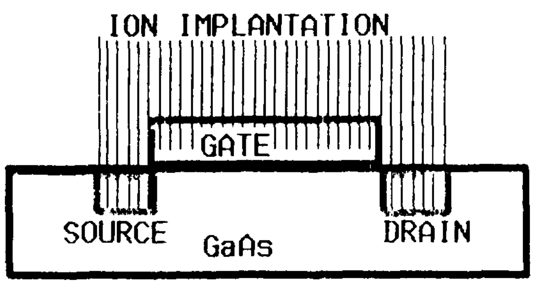


Figure 6. Self-aligned Schottky gate.

Impurity-induced disorder is a very important phenomenon for use in engineering electronic devices using superlattices. We discussed it in an earlier report* and plan to present a fuller treatment of Japanese research on this topic at a later date, so the description here is brief. It is found that if zinc is diffused into a GaAs/AlGaAs superlattice, the superlattice will be destroyed, and in its place there will be a crystalline alloy with Al and Ga atoms randomly distributed over the cation lattice sites. Naturally the alloy concentration is the same as the amounts present in the superlattice. The important point is that the superlattice of the same average composition has an electronic energy band gap and, importantly, an optical index of refraction, different from the alloy. Since techniques exist to either inhibit or enhance the disordering, it is possible to control the spatial distribution of the disordering on a very fine scale, for example, by ion implantation. This means that the spatial configuration of a semiconductor laser and optical waveguide can be written with a focussed ion beam. Workers in this group at OJRL have done exactly that and demonstrated a number of interesting lasers. They also investigated damage induced by the implantation and disordering processes, concluding that the processes did not prevent the formation of high quality devices. This technique might be regarded as a subset of Professor H. Kroemer's proposed "bandgap engineering." It is an important new technique that will surely be widely used in the future.

Highlights of the contributions of the Applied Surface Physics group are:

- Measurements by X-ray photoelectron spectroscopy (XPS), reflection high-energy electron diffraction (RHEED), and high energy ion scattering to completely characterize formation and thermal instability of Au/GaAs interfaces.

- Introduction and fabrication of a new type of laser, index-guided buried multi-quantum-well (BMQW) lasers, using Zn diffusion induced superlattice disordering.

- Development of a new self-aligned Schottky gate material for GaAs MESFETs, namely, lanthanum hexaboride.

*Wright, G.B. 1986. Eighteenth solid state devices and materials meeting: A showcase for Japanese electronics research. *Scientific Bulletin* 11(3): 90–100.

CHARACTERIZATION

The name of this group is meant to describe the activities of measuring the properties of the semiconductor materials that have been grown and subjected to various treatments such as ion implantation, composition variation, and application of external magnetic fields during growth. In broad outline, the research themes of this group include study of deep level defects, impurities, effects of melt composition, and impurity-induced disordering. The largest set of papers addressed the deep level defect problem where, for example, as pointed out by Dr. Merz, the possibility of making many diverse kinds of measurements on material whose growth conditions had been varied over a wide range of well-controlled conditions offered an unparalleled opportunity to obtain a deep understanding of the effect of different growth conditions upon the resulting materials. In particular, the investigation of the deep level electronic defects by photoluminescence (PL), deep level transient spectroscopy (DLTS), infrared absorption (IR), electron spin resonance (ESR), and photocurrent spectra (PCS) has made it possible to develop a unified description of the EL2 center and to distinguish it from some other centers which lie nearby. As this article is being written, some of the latest contributions have not yet appeared in print, and I am indebted to Dr. Tajima for conversations on this point.

In understanding the role of shallow impurities, their origin, and incorporation into the crystals, there are still learning opportunities, in part because the experimental probes for studying them have a higher concentration threshold than one might wish. Studies at OJRL have shown that the spatial distribution of these impurities is important for the homogeneity of important electrical properties of the resulting crystals. We can hope that future projects will continue to bear down on improving our understanding in this area.

The outstanding accomplishments of the characterization and analysis group, in summary, are:

- Observation of very nonuniform spatial distribution of residual donor impurities in semi-insulating GaAs, using secondary ion mass spectroscopy (SIMS).

- Demonstration of the importance of stoichiometry control in obtaining uniform and reproducible electrical activation of Si atoms implanted into semi-insulating GaAs.

- Identification of three different levels in the "EL2 family" by study of DLTS.

- A complete identification of the As antisite EL2 center by a battery of optical, electrical, and other measurements all performed on the same samples.

SUMMARY

The contributions made by OJRL to understanding GaAs growth physics represent, for me, the great progress that can be made by assembling a highly skilled team of outstanding research workers, providing them with the best instrumentation available, and allowing them to do first rate basic science on a goal-oriented problem. The OJRL group communicated with the external research community throughout the project, and I believe they have well satisfied the intention expressed at the highest governmental levels in Japan to contribute in an important way to the international fund of scientific knowledge.

INTERNATIONAL COOPERATION

After the VLSI project, the Optoelectronics Joint Research Laboratory represents the next major government-sponsored research effort in Japan. A very important innovation by the OJRL management and sponsors was the decision to open the project to international cooperation, a decision for which they should be highly praised. The implementation of the cooperation was as follows:

Visiting Researchers

- James L. Merz, University of California at Santa Barbara (UCSB) (U.S.A.), August–December 1985.
- Francois Brillouet, CNET Laboratoire de Bagneux (France), August–October 1986.
- Hans-Jochen Wolf, Siemens AG Erlangen (FRG), October–November 1986.

International Cooperative Research

- Dieter Bimberg, Technische Universitat, Berlin (FRG)
- James L. Merz, UCSB (U.S.A.)
- W. Ruhle, Max-Planck Institut (FRG)

Foreign Visitors

North America	138 Groups
Europe	117
Asia	25

Given a research staff of only about 50 researchers, we see that the hospitality afforded so many visitors represented a major contribution.

FUTURE WORK

After such fine contributions, it is painful to see the Laboratory disbanded, and natural to ask, will there be a follow-on in the form of a new project? It seems that some of the companies involved will form a project of their own, and that there will be a small laboratory at Tsukuba. We were told that one area of research may be on structures with lateral spatial quantization, such as "quantum wires" and "artificial atoms." After OJRL's accomplishments, we will all await with high expectations the development of the follow-on project.

ACKNOWLEDGMENTS

I would like to thank the management of OJRL, Dr. Iizuka, Dr. Hirano, and Dr. Hayashi, for their hospitality on numerous occasions and for generously supplying me with much of the information on which this article is based. Dr. Tajima kindly answered many questions for me and told me of as yet unpublished progress on the EL2 problem. Dr. Merz also gave generously of his time, wrote an outstanding article for our *Scientific Bulletin*, and served as an ideal first link in the international cooperation program.

Appendix

BIBLIOGRAPHY OF ENGLISH LANGUAGE PUBLICATIONS

Group 1 – Bulk Crystal Growth

1 **K. Terashima, H. Nakajima, and T. Fukuda.** LEC growth technique for homogeneous undoped semi-insulating GaAs single crystals with in-situ melt purification process. *Jpn. J. Appl. Phys.* 21 (1982) L452–54.

2 **T. Fukuda.** Growth of undoped semi-insulating GaAs single crystal. Proceedings of the 14th Conference (1982 International) on Solid State Devices, Tokyo. *Jpn. J. Appl. Phys.* 22 (1983), Suppl. 22-1, 413–18.

3 **T. Matsumura, H. Emori, K. Terashima, and T. Fukuda.** Resistivity, Hall mobility and leakage current variations in undoped semi-insulating GaAs crystal grown by LEC method. *Jpn. J. Appl. Phys.* 22 (1983) L154-56.

4 **T. Obokata, H. Emori, and T. Fukuda.** Saddle-type bow of as-cut GaAs wafers. *Jpn. J. Appl. Phys.* 22 (1983) L168–70.

5 **K. Terashima, T. Katsumata, F. Orito, T. Kikuta, and T. Fukuda.** Electrical resistivity of undoped GaAs single crystals grown by magnetic field applied LEC technique. *Jpn. J. Appl. Phys.* 22 (1983) L325–27.

6 **T. Fukuda, K. Terashima, T. Katsumata, F. Orito, and T. Kikuta.** Growth and electrical properties of gallium arsenide single crystal by magnetic field applied LEC technique. *Extended Abstracts of the 15th Conference on Solid State Devices and Materials, Tokyo* (1983) 153–56.

7 **K. Terashima and T. Fukuda.** A new magnetic-field applied pulling apparatus for LEC GaAs single crystal growth. *J. Cryst. Growth* 63 (1983) 423–25.

8 **K. Terashima and T. Fukuda.** Growth and characterization of undoped GaAs single crystals by a new magnetic field applied LEC technique. *Proceedings of the Symposium on III-V Opto-Electronics Epitaxy and Device Related Processes* 83-13 (1983) 79–85. The Electrochemical Society.

9 **T. Fukuda, K. Terashima, and H. Nakajima.** In-situ purification growth of undoped semi-insulating GaAs single crystals. Int. Symp. GaAs and Related Compounds, Albuquerque (1982). *Inst. Phys. Conf. Ser.* No. 65 (1983) 23–29.

10 **H. Emori, T. Matsumura, T. Kikuta, and T. Fukuda.** Effect of ambient gas on undoped LEC GaAs crystal. *Jpn. J. Appl. Phys.* 22 (1983) 1652–55.

11 **T. Shimada, K. Terashima, H. Nakajima, and T. Fukuda.** Growth of low and homogeneous dislocation density GaAs crystal by improved LEC technique. *Jpn. J. Appl. Phys.* 23 (1984) L23–25.

12 **K. Terashima, T. Katsumata, F. Orito, and T. Fukuda.** Vertical magnetic field applied LEC apparatus for large diameter GaAs single crystal growth. *Jpn. J. Appl. Phys.* 23 (1984) L302–4.

13 **K. Terashima, F. Orito, T. Katsumata, and T. Fukuda.** Effect of magnetic field on residual impurity concentration in LEC GaAs single crystal. *Jpn. J. Appl. Phys.* 23 (1984) L485–87.

14 **T. Shimada, T. Obokata, and T. Fukuda.** Growth and resistivity characteristics of undoped semi-insulating GaAs crystals with low dislocation density. *Jpn. J. Appl. Phys.* 23 (1984) L441–44.

15 **T. Obokata, T. Matsumura, K. Terashima, F. Orito, T. Kikuta, and T. Fukuda.** Improved uniformity of resistivity distribution in LEC semi-insulating GaAs produced by annealing. *Jpn. J. Appl. Phys.* 23 (1984) L602–5.

16 **H. Emori, K. Terashima, F. Orito, T. Kikuta, and T. Fukuda.** Effect of ambient gas on LEC undoped semi-insulating GaAs. *Semi-Insulating III-V Materials: Kah-nee-ta 1984,* ed. D.C. Look and J.S. Blakemore, Shiva Publishing (1984) 111–17.

17 **H. Emori, T. Kikuta, T. Inada, T. Obokata, and T. Fukuda.** Effect of water content of B_2O_3 encapsulant on semi-insulating LEC GaAs crystal. *Jpn. J. Appl. Phys.* 24 (1985) L291–93.

18 **T. Matsumura, T. Obokata, and T. Fukuda.** Two-dimensional microscopic uniformity of resistivity in semi-insulating GaAs. *J. Appl. Phys.* 57 (1985) 1182–85.

19 **H. Miyairi, T. Inada, T. Obokata, M. Nakajima, T. Katsumata, and T. Fukuda.** Inhomogeneity of resistivity in In-doped dislocation-free semi-insulating LEC GaAs. *Jpn. J. Appl. Phys.* 24 (1985) L729–32.

20 **T. Obokata, T. Katsumata, and T. Fukuda.** Influence of melt composition on uniformity of electrical properties in semi-insulating LEC GaAs. *Jpn. J. Appl. Phys.* 24 (1985) L785–88.

21 **H. Okada, T. Katsumata, T. Inada, M. Nakajima, T. Obokata, and T. Fukuda.** Influences of native defect EL2 on uniformity of electrical properties in LEC dislocation free GaAs crystals. *Intern. Conf. on Gettering and Defect Engineering in Semiconductor Technology* 1 (1985) 325.

22 **T. Katsumata, T. Obokata, M. Nakajima, and T. Fukuda.** Observations of inhomogeneities in dislocated and In-doped dislocation free GaAs crystals by newly developed video-enhanced IR topography. *Defect Recognition and Image Processing in III-V Compounds,* edited by J.P. Fillard. (Elsevier, 1985) 149–56.

23 **T. Katsumata and T. Fukuda.** New video-enhanced contrast infrared topograph apparatus for evaluation of GaAs crystals. *Rev. Sci. Instrum.* 57 (1986) 202–5.

24 **K. Terashima, A. Yahata, and T. Fukuda.** Growth condition dependence of EL2 concentrations in magnetic field applied liquid-encapsulated Czochralski GaAs crystals. *J. Appl. Phys.* 59 (1986) 982–84.

25 **S. Ozawa, H. Miyairi, M. Nakajima, and T. Fukuda.** Growth and characterization of undoped dislocation free GaAs by arsenic ambient controlled LEC with the aid of X-ray imaging system. *Inst. Phys. Conf. Ser.* No. 79 (1986) 25–30.

26 **T. Obokata, H. Okada, T. Katsumata, and T. Fukuda.** Effect of carbon concentration on thermal conversion in semi-insulating GaAs. *Jpn. J. Appl. Phys.* 25 (1986) L179–81.

27 **F. Orito, H. Okada, M. Nakajima, T. Fukuda, and T. Kajimura** (Hitachi Ltd.). Growth of silicon-doped dislocation-free GaAs crystals by the LEC technique for optical device applications. *J. Electron. Mater.* 15 (1986) 87–90.

28 **T. Inada, T. Sato, K. Ishida, T. Fukuda, and S. Takahashi** (Hitachi Ltd.). Homogeneous semi-insulating GaAs crystal growth by a new LEC technique with As injection into melt during growth. *J. Electron. Mater.* 15 (1986) 169–73.

29 **H. Okada, T. Katsumata, T. Obokata, T. Fukuda, and W. Susaki** (Mitsubishi Electric). LEC growth of undoped SI GaAs single crystals for opto-electronic application. *J. Cryst. Growth* 75 (1986) 319–22.

30 **T. Fujii, M. Nakajima, and T. Fukuda.** Growth of Si and In double-doped dislocation-free conductive GaAs crystal by the LEC technique. *Materials Lett.* 4 (1986) 189–93.

31 **T. Inada, S. Ozawa, T. Fujii, T. Obokata, K. Ishida, and T. Fukuda.** Effects of growth conditions on MESFET characteristics in semi-insulating GaAs crystals grown by improved LEC techniques. *Semi-Insulating III-V Materials, Hakone* (1986) 23–28.

32 **S. Ozawa and T. Fukuda.** In-situ observation of LEC GaAs solid-liquid interface by a newly developed X-ray imaging system. *J. Cryst. Growth* 76 (1986) 323–27.

33 **T. Katsumata, H. Okada, T. Kikuta, T. Fukuda, and T. Ogawa** (Gakusyuin Univ.). Micro-defect in LEC GaAs observed with the infrared scattering and their correlation with the infrared transmission image. *Semi-Insulating III-V Materials, Hakone* (1986) 145–50.

34 **S. Ozawa, T. Inada, T. Kimura, H. Miyairi, and T. Fukuda.** Homogeneity improvement of semi-insulating LEC GaAs and InP crystals by applying strong magnetic field during growth. *Semi-Insulating III-V Materials, Hakone* (1986) 53–58.

35 **T. Katsumata, H. Okada, T. Kimura, and T. Fukuda.** Influence of melt composition on the longitudinal distribution of midgap native donor concentration in semi-insulating liquid encapsulated Czochralski GaAs crystal. *J. Appl. Phys.* 60 (1986) 3105–10.

36 **T. Kimura, T. Katsumata, M. Nakajima, and T. Fukuda.** The effect of strong magnetic field on homogeneity in LEC GaAs single crystal. *J. Cryst. Growth* 79 (1986) 264.

37 **H. Miyairi, T. Inada, M. Eguchi, and T. Fukuda.** Growth and properties of InP single crystals grown by the magnetic field applied LEC method. *J. Cryst. Growth* 79 (1986) 291.

38 **H. Miyairi, S. Ozawa, M. Eguchi, and T. Fukuda.** Observation of microscopic defects in dislocation-free GaAs crystals by eutectic etching. *J. Cryst. Growth* 76 (1986) ˆ38–94.

39 **T. Inada, T. Fujii, M. Eguchi, and T. Fukuda.** Technique for the direct synthesis and growth of indium phosphide by the liquid phosphorus encapsulated Czochralski method. *Appl. Phys. Lett.* 50 (1987) 86–88.

40 **T. Inada, T. Fujii, T. Kikuta, and T. Fukuda.** Growth of semi-insulating GaAs crystals with low carbon concentration using pyrolytic boron nitride coated graphite. To be published in *Appl. Phys. Lett.*

41 **S. Ozawa, T. Kimura, J. Kobayashi, and T. Fukuda.** Programmed magnetic field applied liquid encapsulated Czochralski crystal growth. To be published in *Appl. Phys. Lett.*

42 **T. Katsumata, H. Okada, T. Obokata, and T. Fukuda.** The relation between infrared absorption and resistivity in LEC semi-insulating GaAs crystals. To be published in *J. Appl. Phys.*

43 **T. Fukuda.** Growth of high quality semi-insulating GaAs for LSI application. *Semiconductor and Semimetals Series.*

44 **T. Inada, T. Fujii, M. Eguchi, and T. Fukuda.** New direct synthesis technique for indium phosphide using liquid phosphorus. To be published in *J. Cryst. Growth.*

45 **H. Okada, T. Katsumata, M. Eguchi, and T. Fukuda.** A new apparatus for double-crucible LEC GaAs crystal growth. To be published in *J. Cryst. Growth.*

46 **S. Ozawa, T. Yokotsuka, T. Fujii, J. Kobayashi, T. Fukuda, S. Kojima*, and M. Ikeda*** (*Furukawa Electric). In-doped GaAs substrate assessment for thin film applications. To be published in *Materials Lett.*

47 **H. Okada, T. Katsumata, T. Inada, T. Obokata, and T. Fukuda.** Influence of changes in growth conditions in electrical uniformity of semi-insulating dislocation-free LEC GaAs crystals. Submitted to *J. Cryst. Growth.*

48 **T. Inada, T. Fujii, and T. Fukuda.** Native defect related inhomogeneity in characteristics of GaAs FETs fabricated on annealed dislocation free substrates. To be published in *Appl. Phys. Lett.*

49 **T. Fujii, M. Nakajima, and T. Fukuda.** Growth cells of heavily In-doped LEC GaAs crystals. Submitted to *J. Cryst. Growth.*

50 **T. Fujii, M. Eguchi, T. Inada, and T. Fukuda.** Effects of crucible materials on undoped LEC GaAs crystals. Submitted to *J. Cryst. Growth.*

51 **T. Kimura, H. Okada, and T. Fukuda.** High speed pulling of GaAs single crystal using magnetic field applied LEC technique. Submitted to *J. Cryst. Growth.*

52 **S. Ozawa, H. Miyairi, J. Kobayashi, and T. Fukuda.** Effects of arsenic ambient controlled LEC crystal growth technique in residual impurities. Submitted to *J. Cryst. Growth.*

53 **T. Kimura, S. Ozawa, T. Obokata, and T. Fukuda.** Effects of melt aspect ratio on temperature fluctuation in GaAs melt under vertical magnetic field. Submitted to *J. Cryst. Growth.*

54 **T. Obokata, T. Sato, and T. Fujii.** Thermal annealing of semi-insulating GaAs under controlled arsenic pressure. To be published in *Appl. Phys. Lett.*

55 **T. Fujii, M. Nakajima, T. Fukuda, K. Nitta*, and T. Komatsubara*** (*Toshiba Corp.). Growth and LED evaluation of N-type conductive LEC GaAs co-doped with In and Si. To be published in *J. Electric Materials.*

Group 2 – Maskless Ion Implantation

1 **E. Miyauchi, Y. Bamba, A. Takamori, and T. Furuya.** Deposition of low-energy liquid metal (Sn) ion beam on GaAs and its application to doping in MBE-growing GaAs film. *Proc. of the 1st Symposium on Ion Beam Technology, Hosei Univ.* (1982) 73–76.

2 **E. Miyauchi, H. Hashimoto, and T. Utsumi.** Au–Si–Be liquid metal ion source for maskless ion implantation. *Jpn. J. Appl. Phys.* 22 (1983) L225–26.

3 **E. Miyauchi, H. Arimoto, H. Hashimoto, T. Furuya, and T. Utsumi.** A 100 kV maskless ion-implantation system with an Au–Si–Be liquid metal ion source for III–V compound semiconductors. *Jpn. J. Appl. Phys.* 22 (1983) L287–88.

4 **Y. Bamba, E. Miyauchi, K. Kuramoto, A. Takamori, and T. Furuya.** Sn ion doping during GaAs MBE with field ion gun. *Jpn. J. Appl. Phys.* 22 (1983) L331–32.

5 **E. Miyauchi, H. Arimoto, Y. Bamba, A. Takamori, H. Hashimoto, and T. Utsumi.** Lateral spreads of Be and Si in GaAs implanted with a maskless ion implantation system. *Jpn. J. Appl. Phys.* 22 (1983) L423–25.

6 **A. Takamori, E. Miyauchi, H. Arimoto, Y. Bamba, and H. Hashimoto.** GaAs molecular beam epitaxy on Be implanted GaAs layers. *Jpn. J. Appl. Phys.* 22 (1983) L520–22.

7 **Y. Bamba, E. Miyauchi, H. Arimoto, K. Kuramoto, A. Takamori, and H. Hashimoto.** Focused Si ion implantation in GaAs. *Jpn. J. Appl. Phys.* 22 (1983) L650–52.

8 **H. Arimoto, A. Takamori, E. Miyauchi, and H. Hashimoto.** Novel method for measuring intensity distribution of focused ion beams. *Jpn. J. Appl. Phys.* 22 (1983) L780–82.

9 **E. Miyauchi, H. Arimoto, H. Hashimoto, and T. Utsumi.** Selective Si and Be implantation in GaAs using a 100 kV mass-separating focused ion beam system with an Au-Si-Be liquid metal ion source. *J. Vac. Sci. & Technol.* B1 (1983) 1113–16.

10 **H. Arimoto, A. Takamori, E. Miyauchi, and H. Hashimoto.** Pd-Ni-Si-Be-B liquid metal ion source for maskless ion implantation. *Jpn. J. Appl. Phys.* 23 (1984) L165–66.

11 **Y. Bamba, E. Miyauchi, H. Arimoto, K. Kuramoto, A. Takamori, and H. Hashimoto.** A high beam current density effect on Si implantation in GaAs. *Proc. of the 15th Symposium on Ion Implantation and Submicron Fabrication, Wako* (1984) 117–20.

12 **Y. Bamba, E. Miyauchi, H. Arimoto, A. Takamori, and H. Hashimoto.** Reduced damage generation in GaAs implanted with focused Be ions. *Jpn. J. Appl. Phys.* 23 (1984) L515–17.

13 **A. Takamori, E. Miyauchi, H. Arimoto, Y. Bamba, and H. Hashimoto.** GaAs growth using an MBE system connected with a 100 kV UHV maskless ion implanter. *Jpn. J. Appl. Phys.* 23 (1984) L599–601.

14 **H. Hashimoto and E. Miyauchi.** Focused ion implantation for optoelectronic integrated circuits. *Extended Abstracts of the 16th (1984 International) Conference on Solid State Devices and Materials, Kobe* (1984) 121–24.

15 **E. Miyauchi, H. Arimoto, Y. Bamba, A. Takamori, and H. Hashimoto.** Computer control of maskless ion implanter with Au-Si-Be LM ion source for III–V compound semiconductors. *Nucl. Instrum. & Methods* B6 (1985) 183–89.

16 **E. Miyauchi and H. Hashimoto.** Maskless ion implantation technology for III–V compound semiconductors. *Nucl. Instrum. & Methods* B7/8 (1985) 851–57.

17 **H. Arimoto, A. Takamori, E. Miyauchi, and H. Hashimoto.** Formation of submicron isolation in GaAs by implanting a focused boron ion beam emitted from a Pd-Ni-Si-Be-B LM ion source. *J. Vac. Sci. & Technol.* B3 (1985) 54–57.

18 **Y. Bamba, E. Miyauchi, M. Nakajima, H. Arimoto, A. Takamori, and H. Hashimoto.** Si depth profiles in focused-ion-beam-implanted GaAs. *Jpn. J. Appl. Phys.* 24 (1985) L6–8.

19 **H. Hashimoto, A. Takamori, T. Morita, H. Arimoto, Y. Bamba, and E. Miyauchi.** GaAs MBE with focused ion implantation doping. *Proc. of the 16th Symposium on Ion Implantation and Submicron Fabrication, Wako* (1985) 45–48.

20 **H. Arimoto, E. Miyauchi, and H. Hashimoto.** Emission characteristics of Au-Si-Be LM ion source. *Jpn. J. Appl. Phys.* 24 (1985) L288–90.

21 **A. Takamori, E. Miyauchi, H. Arimoto, Y. Bamba, T. Morita, and H. Hashimoto.** Growth-interrupted interfaces in multilayer MBE growth of gallium arsenide. *Jpn. J. Appl. Phys.* 24 (1985) L414–16.

22 **A. Takamori, E. Miyauchi, H. Arimoto, T. Morita, Y. Bamba, and H. Hashimoto.** Optical properties of pattern-doped GaAs/AlGaAs grown by an MBE system equipped with a focused ion beam implanter. *Inst. Phys. Conf. Ser.* No. 79 (1986) 247–52.

23 **E. Miyauchi, T. Morita, A. Takamori, H. Arimoto, Y. Bamba, and H. Hashimoto.** Maskless ion beam writing of precise doping patterns with Be and Si for molecular beam epitaxially grown multilayer GaAs. *J. Vac. Sci. & Technol.* B4 (1986) 189–93.

24 **E. Miyauchi and H. Hashimoto.** Application of focused ion beam technology to maskless ion implantation in a molecular beam epitaxy grown GaAs or AlGaAs epitaxial layer for three-dimensional pattern doping crystal growth. *J. Vac. Sci. & Technol.* A4 (1986) 933–38.

25 **Y. Bamba, E. Miyauchi, H. Arimoto, T. Morita, A. Takamori, and H. Hashimoto.** Novel submicron isolation technique of GaAs active layer using FIBI-MBE. *Proc. of SPIE–The International Society for Optical Engineering* 632 (1986) 189–95.

26 **E. Miyauchi, T. Morita, H. Arimoto, A. Takamori, Y. Bamba, and H. Hashimoto.** Automated FIB control technology for maskless ion implantation. *Proc. of the 17th Symposium on Ion Implantation and Submicron Fabrication, Wako* (1986) 133–36.

27 **H. Arimoto, E. Miyauchi, and H. Hashimoto.** Emission stability of Au–Si–Be LM ion source in various gas environments. *Proc. of the 10th Symposium on Ion Sources and Ion–Assisted Technology, Tokyo* (1986) 9–12.

28 **H. Arimoto, T. Morita, E. Miyauchi, and H. Hashimoto.** Positional stability of focused ion beams. *Jpn. J. Appl. Phys.* 25 (1986) L507–9.

29 **H. Arimoto, E. Miyauchi, and H. Hashimoto.** Emission stability of Au–Si–Be LM ion source in various gas environments. *Jpn. J. Appl. Phys.* 25 (1986) L567–68.

30 **T. Morita, E. Miyauchi, H. Arimoto, A. Takamori, Y. Bamba, and H. Hashimoto.** Geometrical design of an alignment mark for maskless ion implantation in GaAs. *J. Vac. Sci. & Technol.* B4 (1986) 829–32.

31 **H. Arimoto, T. Morita, A. Takamori, Y. Bamba, E. Miyauchi, and H. Hashimoto.** Formation of buried isolation layer by implanting focused B ion beam in GaAs multilayer using FIBI-MBE system. *Extended Abstracts of the 18th (1986 International) Conference on Solid State Devices and Materials, Tokyo* (1986) 137–40.

32 **H. Hashimoto.** An enclosed through-process system of OEIC fabrication. *The 3rd German–Japan Forum on Information Technology, Tokyo* (1986).

33 **T. Morita, E. Miyauchi, H. Arimoto, A. Takamori, Y. Bamba, and H. Hashimoto.** Geometrical design of an alignment mark for focused ion beam implantation in GaAs using Monte Carlo simulation of ion trajectories. *J. Vac. Sci. & Technol.* B5 (1987) 236–40.

34 **H. Hashimoto and E. Miyauchi.** Finely focused ion beam technology in III–V compound semiconductors. To be published in *Nucl. Instrum. & Methods.*

35 **H. Hashimoto and E. Miyauchi.** Focused ion beam implantation doping GaAs/AlGaAs MBE growth. To be published in *J. Vac. Sci. & Technol.*

36 **H. Arimoto, E. Miyauchi, and H. Hashimoto.** Effect of ambient gases on emission properties of Pd–Ni–Si–Be–B LM ion source. *Jpn. J. Appl. Phys.* 26 (1987) L103–4.

37 **A. Takamori, S. Sugata, K. Asakawa, E. Miyauchi, and H. Hashimoto.** Cleaning of MBE GaAs substrates by hydrogen radical beam irradiation. *Jpn. J. Appl. Phys.* 26 (1987) L158–60.

38 **E. Miyauchi, H. Arimoto, T. Morita, and H. Hashimoto.** Dependence of focused ion beam intensity profile on ion species at several orders of magnitude below the peak intensity. *Jpn. J. Appl. Phys.* 26 (1987) L145–47.

39 **T. Morita, H. Arimoto, E. Miyauchi, and H. Hashimoto.** Novel methods for measuring diameter of focused ion beam. *Jpn. J. Appl. Phys.* 26 (1987) 289–92.

40 **H. Hashimoto, A. Takamori, H. Arimoto, T. Morita, and E. Miyauchi.** Focused ion beam doping for GaAs MBE growth. To be published in *Microelectronic Engineering Journal.*

41 **T. Morita, H. Arimoto, E. Miyauchi, and H. Hashimoto.** Alignment accuracy of focused ion beam implantation. To be published in *Jpn. J. Appl. Phys.*

42 **T. Morita, A. Takamori, H. Arimoto, E. Miyauchi, and H. Hashimoto.** Alignment signal from a mark deformed by molecular beam epitaxial overgrowth for focused ion beam implantation. Submitted to *Jpn. J. Appl. Phys.*

43 **H. Arimoto, T. Takamori, K. Ishida, H. Nakashima, E. Miyauchi, and H. Hashimoto.** Au–Zn–Si liquid metal ion source emitting multiple p– and n–type ion species for compositional disordering of GaAs/AlGaAs superlattice. Submitted to 1987 International Symposium on Electron, Ion, and Photon Beams.

44 **H. Arimoto, E. Miyauchi, and H. Hashimoto.** Effects of ambient gases on ion emission stability of LM ion source. Submitted to *J. Appl. Phys.*

Group 3 – Epitaxial Growth

1 **K. Yamanaka, S. Naritsuka, M. Mannoh, K. Shinozaki, T. Yuasa, Y. Nomura, M. Mihara, and M. Ishii.** Influence of growth conditions and allow composition on deep electron traps of MBE grown n–AlGaAs. *Extended Abstracts of the 15th Conference on Solid State Devices and Materials, Tokyo* (1983) 157–60.

2 **T. Yuasa, S. Naritsuka, M. Mannoh, K. Shinozaki, K. Yamanaka, Y. Nomura, M. Mihara, and M. Ishii.** Raman scattering measurement of the free–carrier concentration in $Al_xGa_{1-x}As$. *Extended Abstracts of the 15th Conference on Solid State Devices and Materials, Tokyo* (1983) 173–76.

3 **Y. Nomura, M. Mannoh, M. Mihara, S. Naritsuka, K. Yamanaka, T. Yuasa, and M. Ishii.** Effect of group V/III flux ratio on optical and electrical properties of Si–doped $Al_xGa_{1-x}As$ grown by molecular beam epitaxy. *Proceedings of the Symposium on III–V Optoelectronics Epitaxy and Device Related Process* 83–13 (1983) 159–163. The Electrochemical Society.

4 **S. Takagishi and H. Mori.** Effect of operating pressure on the properties of GaAs grown by low–pressure MOCVD. *Jpn. J. Appl. Phys.* 22, no. 12 (1983) L795–97.

5 **S. Takagishi and H. Mori.** Epitaxial growth of high purity GaAs by low–pressure MOCVD. *Jpn. J. Appl. Phys.* 23, no. 2 (1984) L100–2.

6 **S. Naritsuka, K. Yamanaka, M. Mihara, and M. Ishii.** Effects of growth conditions on electron trap concentrations in Si–doped $Al_{0.2}Ga_{0.8}As$ grown by MBE. *Jpn. J. Appl. Phys.* 23 (1984) L112–14.

7 **M. Mihara, Y. Nomura, M. Mannoh, K. Yamanaka, S. Naritsuka, K. Shinozaki, T. Yuasa, and M. Ishii.** Composition dependence on photoluminescence of $Al_xGa_{1-x}As$ grown by molecular beam epitaxy. *J. Appl. Phys.* 55 (1984) 3760–64.

8 **M. Mihara, Y. Nomura, M. Mannoh, K. Yamanaka, S. Naritsuka, K. Shinozaki, T. Yuasa, and M. Ishii.** Defect–related emissions in photoluminescence spectra of $Al_xGa_{1-x}As$ grown by molecular beam epitaxy. *J. Appl. Phys.* 55 (1984) 3765–68.

9 **K. Yamanaka, S. Naritsuka, M. Mannoh, T. Yuasa, Y. Nomura, M. Mihara, and M. Ishii.** Influence of growth conditions and alloy composition on deep electron traps of n–$Al_xGa_{1-x}As$ grown by MBE. *J. Vac. Sci. & Technol.* B2 (1984) 229–32.

10 **Y. Nomura, M. Mannoh, M. Mihara, S. Naritsuka, K. Yamanaka, T. Yuasa, and M. Ishii.** Effect of group V/III flux ratio on lightly Si–doped $Al_xGa_{1-x}As$ grown by molecular beam epitaxy. *J. Electrochem. Soc.* 131 (1984) 2630–33.

11 **H. Mori and S. Takagishi.** Morphology of GaAs epitaxial layers grown by MOCVD. *J. Cryst. Growth* 69 (1984) 23–28.

12 **H. Mori and S. Takagishi.** Influence of H_2 overpressure on the properties of GaAs grown by low–pressure MOCVD. *Jpn. J. Appl. Phys.* 23 (1984) L877–79.

13 **T. Yuasa, S. Naritsuka, M. Mannoh, K. Shinozaki, K. Yamanaka, Y. Nomura, M. Mihara, and M. Ishii.** Observation of plasmons coupled with optical phonons in n–$Al_xGa_{1-x}As$ by Raman scattering. *Appl. Phys. Lett.* 46 (1985) 176–78.

14 **K. Shinozaki, M. Mannoh, Y. Nomura, N. Mihara, and M. Ishii.** Effects of thermal annealing on Si–doped GaAs grown by molecular beam epitaxy. *J. Appl. Phys.* 57 (1985) 4826–27.

15 **Y. Nomura, K. Shinozaki, K. Asakawa, and M. Ishii.** Lasing characteristics of GaAs/AlGaAs multilayer composing distributed feedback cavity for surface-emitting laser. *Extended Abstracts of the 17th Conference on Solid State Devices and Materials, Tokyo* (1985) 71-74.

16 **K. Kimura, S. Takagishi, S. Horiguchi, K. Kamon, M. Mihara, and M. Ishii.** Low-pressure OMVPE of GaAs using a triethylgallium source. *Extended Abstracts of the 17th Conference on Solid State Devices and Materials, Tokyo* (1985) 201-4.

17 **Y. Nomura, K. Shinozaki, and M. Ishii.** Bound excitons in Si-doped GaAs/$Al_{0.22}Ga_{0.78}As$ single quantum wells. *J. Appl. Phys.* 58 (1985) 1864-66.

18 **M. Mannoh, T. Yuasa, K. Asakawa, K. Shinozaki, and M. Ishii.** Low-threshold MBE GaAs/AlGaAs quantum well lasers with dry-etched mirrors. *Electron. Lett.* 21 (1985) 769-70.

19 **M. Mannoh, T. Yuasa, S. Naritsuka, K. Shinozaki, and M. Ishii.** Pair-groove-substrate GaAs/AlGaAs multiquantum well lasers by molecular beam epitaxy. *Appl. Phys. Lett.* 47 (1985) 728-31.

20 **S. Naritsuka, K. Yamanaka, M. Mannoh, M. Mihara, and M. Ishii.** Effect of arsenic source on electron trap concentrations in MBE-grown $Al_{0.2}Ga_{0.8}As$. *Jpn. J. Appl. Phys.* 24 (1985) 1324-26.

21 **K. Kamon, S. Takagishi, and H. Mori.** Selective epitaxial growth of GaAs by low-pressure MOVPE. *J. Cryst. Growth* 73 (1985) 73-76.

22 **K. Yamanaka, T. Fukunaga, N. Tsukada, K.L.I. Kobayashi, and M. Ishii.** Photocurrent spectroscopic observation of interband transitions in GaAs-AlGaAs quantum wells under an applied high electric field. *Proceedings of the 2nd International Conference on Modulated Semiconductor Structures, Kyoto* (1985) 144-49.

23 **T. Yuasa, K. Asakawa, M. Mannoh, K. Shinozaki, and M. Ishii.** Reactive-ion-beam-etched cavity GaAs-AlGaAs multiquantum well lasers. *Proceedings of the 5th International Conference on Integrated Optics and Optical Fiber Communication, Italy*, 1 (1985) 505-8.

24 **M. Mannoh, Y. Nomura, K. Shinozaki, M. Mihara, and M. Ishii.** Ionized Mg doping in molecular-beam epitaxy of GaAs. *J. Appl. Phys.* 59 (1986) 1092-95.

25 **T. Yuasa, S. Naritsuka, M. Mannoh, K. Shinozaki, K. Yamanaka, Y. Nomura, M. Mihara, and M. Ishii.** Raman scattering from coupled plasmon-LO-phonon modes in n-type $Al_xGa_{1-x}As$. *Phys. Rev.* B33 (1986) 1222-32.

26 **K. Kamon, S. Takagishi, and H. Mori.** Selective embedded growth of $Al_xGa_{1-x}As$ by low-pressure organometallic vapor phase epitaxy. *Jpn. J. Appl. Phys.* 25 (1986) L10-12.

27 **S. Horiguchi, K. Kimura, S. Takagishi, K. Kamon, M. Mihara, and M. Ishii.** Mass-spectrometric study of growth reactions in low-pressure OMVPE of GaAs by in-situ gas sampling. *Inst. Phys. Conf. Ser.* No. 79 (1986) 157-62.

28 T. Yuasa, M. Mannoh, K. Asakawa, K. Shinozaki, and M. Ishii. Dry-etched-cavity pair-groove-substrate GaAs/AlGaAs multiquantum well lasers. *Appl. Phys. Lett.* 48 (1986) 748–50.

29 S. Takagishi, H. Mori, K. Kimura, K. Kamon, and M. Ishii. Epitaxial growth of $Al_xGa_{1-x}As$ by low-pressure MOCVD. *J. Cryst. Growth* 75 (1986) 545–50.

30 M. Mihara, M. Mannoh, K. Shinozaki, S. Naritsuka, and M. Ishii. Photoluminescence of the 78 meV acceptor in GaAs layers grown by molecular beam epitaxy. *Jpn. J. Appl. Phys.* 25 (1986) L611–13.

31 K. Yamanaka, T. Fukunaga, N. Tsukada, K.L.I. Kobayashi, and M. Ishii. Photocurrent spectroscopy in GaAs/AlGaAs multiple quantum wells under a high electric field perpendicular to the heterointerface. *Appl. Phys. Lett.* 48 (1986) 840–42.

32 M. Mashita, S. Horiguchi, M. Shimazu, K. Kamon, M. Mihara, and M. Ishii. The pyrolysis temperature of triethylgallium in the presence of arsine or trimethylaluminum. *J. Cryst. Growth* 77 (1986) 194–99.

33 K. Kamon, M. Shimazu, K. Kimura, M. Mihara, and M. Ishii. Selective growth of $Al_xGa_{1-x}As$ embedded in etched grooves on GaAs by low-pressure OMVPE. *J. Cryst. Growth* 77 (1986) 297–302.

34 K. Yamanaka, T. Fukunaga, N. Tsukada, K.L.I. Kobayashi, and M. Ishii. Photocurrent spectroscopic observation of interband transitions in GaAs–AlGaAs quantum wells under an applied high electric field. *Surface Science* 174 (1986) 250–54.

35 K. Nomura, K. Shinozaki, K. Asakawa, and M. Ishii. GaAs/AlGaAs distributed feedback structure with multiquantum well for surface-emitting laser. *J. Appl. Phys.* 60 (1986) 874–77.

36 K. Kimura, S. Takagishi, S. Horiguchi, K. Kamon, M. Mihara, and M. Ishii. Low-pressure OMVPE of GaAs using triethylgallium. *Jpn. J. Appl. Phys.* 25 (1986) 1393–96.

37 T. Yamada, T. Yuasa, K. Kamon, M. Shimazu, and M. Ishii. Pair-groove-substrate GaAs/AlGaAs multiquantum-well lasers with a self-aligned stripe geometry. *Electron. Lett.* 22 (1986) 1164–66.

38 T. Yuasa, T. Yamada, K. Asakawa, S. Sugata, and M. Ishii. Short cavity GaAs/AlGaAs multiquantum well lasers by dry etching. *Appl. Phys. Lett.* 49 (1986) 1007–9.

39 S. Horiguchi, K. Kimura, K. Kamon, M. Mashita, M. Shimazu, M. Mihara, and M. Ishii. Molecular beam epitaxial growth of GaAs using triethylgallium and arsine. *Jpn. J. Appl. Phys.* 25 (1986) L979–82.

40 T. Yuasa and M. Ishii. Raman scattering study of coupled hole-plasmon-LO-phonon modes in p-type GaAs and p-type $Al_xGa_{1-x}As$. *Phys. Rev.* B35, March (1987).

41 **K. Kimura, S. Horiguchi, K. Kamon, M. Mashita, M. Mihara, and M. Ishii.** Molecular beam epitaxial growth of GaAs using triethylgallium and As_4. *Jpn. Appl. Phys.* 26 (1987) 419–22.

42 **K. Kimura, S. Horiguchi, K. Kamon, M. Shimazu, M. Mashita, M. Mihara, and M. Ishii.** Doping enhancement by excimer laser irradiation in gas source molecular beam epitaxy of GaAs. *Jpn. J. Appl. Phys.* 26 (1987) L38–40.

43 **M. Ishii, K. Kamon, M. Shimazu, M. Mihara, H. Kumabe, and K. Isshiki.** Planar TJS lasers fabricated in semi-insulating GaAs substrates for optoelectronic integrated circuits. To be published in *Electron. Lett.*

44 **K. Kimura, S. Horiguchi, K. Kamon, M. Shimazu, M. Mashita, M. Mihara, and M. Ishii.** Silicon doping from disilane in gas source MBE of GaAs. *J. Crystal Growth* 81 (1987) 276–80.

45 **K. Kanamoto, K. Kimura, S. Horiguchi, M. Mihara, and M. Ishii.** DLTS study of electron traps in n–GaAs grown by gas source molecular beam epitaxy using triethylgallium and AsH_3. To be published in *Jpn. J. Appl. Phys.* (L).

46 **M. Shimazu, K. Kamon, K. Kimura, M. Mashita, M. Mihara, and M. Ishii.** Silicon doping using disilane in low–pressure OMVPE of GaAs. To be published in *J. Crystal Growth.*

47 **T. Yuasa, T. Yamada, K. Asakawa, and M. Ishii.** Very high relaxation oscillation frequency in dry–etched short cavity GaAs/AlGaAs multiquantum well lasers. To be published in *Appl. Phys. Lett.*

48 **K. Yamanaka, S. Naritsuka, K. Kanamoto, M. Mihara, and M. Ishii.** Electron traps in AlGaAs grown by molecular beam epitaxy. To be published in *J. Appl. Phys.*

49 **T. Yuasa, M. Mannoh, T. Yamada, S. Naritsuka, K. Shinozaki, and M. Ishii.** Characteristics of molecular beam epitaxially grown pair–groove–substrate GaAs/AlGaAs multiquantum well lasers. To be published in *J. Appl. Phys.*

50 **K. Kamon, M. Shimazu, K. Kimura, M. Mihara, and M. Ishii.** Orientation dependence of GaAs growth in low–pressure OMVPE. To be published in *J. Crystal Growth.*

51 **M. Mashita, S. Horiguchi, M. Shimazu, M. Mihara, and M. Ishii.** A novel method for gas temperature measurements in low pressure OMVPE reactors. Submitted to *Jpn. J. Appl. Phys.*

Group 4 – Applied Surface Physics

1 **K.L.I. Kobayashi, H. Daimon, N. Watanabe, M. Taniguchi, S. Suga, H. Nakashima, and Y. Murata.** Evidence of interference between direct and inner–shell–deexcitation photoemission in semiconductors. *Physica* 117&118 B+C (1983) 57–59.

2 **K.L.I. Kobayashi, N. Watanabe, T. Narusawa, and H. Nakashima.** Formation and thermal stability of Au–GaAs(001) interfaces studied by angle resolved XPS and Rutherford backscattering. *Extended Abstracts of the 15th Conference on Solid State Devices and Materials, Tokyo* (1983) 165–68.

3 **K.L.I. Kobayashi, N. Watanabe, H. Nakashima, M. Kubota, H. Daimon, and Y. Murata.** Resonant photoemission from Al–GaAs(110) interfaces. *Phys. Rev. Lett.* 52 (1984) 160–63.

4 **T. Narusawa, N. Watanabe, K.L.I. Kobayashi, and H. Nakashima.** Structure study of Au–GaAs(001) interfaces by HEIS, XPS and RHEED. *J. Vac. Sci. & Technol.* A2 (1984) 538–41.

5 **T. Fukuzawa, S. Semura, H. Saito, T. Ohta, Y. Uchida, and H. Nakashima.** GaAlAs buried multiquantum well lasers fabricated by diffusion–induced disordering. *Appl. Phys. Lett.* 45 (1984) 1–3.

6 **T. Narusawa, K.L.I. Kobayashi, and H. Nakashima.** Characterization of semiconductor surfaces and interfaces by high energy ion scattering. *Extended Abstracts of the 16th (1984 International) Conference on Solid State Devices and Materials, Kobe* (1984) 289–92.

7 **T. Narusawa, K.L.I. Kobayashi, and H. Nakashima.** High energy ion channeling study of MBE–grown GaAs(001) surface structures. *Jpn. J. Appl. Phys.* 24 (1985) L98–100.

8 **H. Nakashima, T. Narusawa, S. Semura, and K.L.I. Kobayashi.** Lattice location of Zn in Zn–diffused GaAlAs using particle–induced X–ray emission. *Proc. of the 13th Intern. Conf. Defects in Semiconductors, Coronado, 1984* (Metallurgical Soc. AIME, Pennsylvania, 1985) 463–69.

9 **K.L.I. Kobayashi, N. Watanabe, H. Nakashima, M. Kubota, H. Daimon, and Y. Murata.** Resonant photoemission as a local probe for interface–An application to Al–GaAs (110). *Proceedings of the 17th International Conference on the Physics of Semiconductors* (Springer–Verlag, New York, 1985) 167–70.

10 **S. Semura, T. Ohta, T. Kuroda, and H. Nakashima.** AlGaAs/GaAs buried multiquantum well lasers with a reactive ion etched window facet. *Jpn. J. Appl. Phys.* 24 (1985) L463–65.

11 **T. Narusawa, Y. Uchida, K.L.I. Kobayashi, T. Ohta, M. Nakajima, and H. Nakashima.** Lattice location of Si in MBE–grown highly Si–doped GaAs layers. *Inst. Phys. Conf. Ser.* No. 74 (1985) 127–32.

12 **N. Watanabe, T. Fukunaga, K.L.I. Kobayashi, and H. Nakashima.** Surface defect formation in GaAs layers grown on intentionally contaminated substrate by molecular beam epitaxy. *Jpn. J. Appl. Phys.* 24 (1985) L498–500.

13 **T. Fukunaga, K.L.I. Kobayashi, and H. Nakashima.** Photoluminescence from AlGaAs–GaAs single quantum wells with growth interrupted heterointerfaces grown by molecular beam epitaxy. *Jpn. J. Appl. Phys.* 24 (1985) L510–12.

14 **S. Semura, T. Ohta, T. Kuroda, and H. Nakashima.** AlGaAs/GaAs multiquantum well lasers with buried multiquantum well optical guide. *Jpn. J. Appl. Phys.* 24 (1985) L548–50.

15 **H. Nakashima, S. Semura, T. Ohta, and T. Kuroda.** AlGaAs window stripe buried multiquantum well lasers. *Jpn. J. Appl. Phys.* 24 (1985) L647–49.

16 **H. Nakashima.** Enhanced disordering of AlGaAs superlattice and its application to fabrication of index-guided multiquantum well lasers. *Extended Abstracts of the 17th Conference on Solid State Devices and Materials, Tokyo* (1985) 57–61.

17 **T. Yokotsuka, Y. Uchida, K.L.I. Kobayashi, T. Narusawa, and H. Nakashima.** New self-aligned gate material; LaB_6 for GaAs-IC. *Extended Abstracts of the 17th Conference on Solid State Devices and Materials, Tokyo* (1985) 437–40.

18 **H. Nakashima, S. Semura, T. Ohta, Y. Uchida, H. Saito, T. Fukuzawa, T. Kuroda, and K.L.I. Kobayashi.** Device characteristics of GaAlAs buried-multiquantum-well lasers fabricated by Zn-diffusion-induced disordering. *IEEE J. Quantum Electron.* QE-21 (1985) 629–33.

19 **K.L.I. Kobayashi, N. Watanabe, T. Narusawa, and H. Nakashima.** Studies of Au-GaAs(001) interfaces prepared by molecular beam epitaxy. *J. Appl. Phys.* 58 (1985) 3758–65.

20 **N. Watanabe, K.L.I. Kobayashi, T. Narusawa, and H. Nakashima.** Studies of Au-GaAs(001) interfaces prepared by molecular beam epitaxy II. Thermal stability of Au-GaAs(001) interface. *J. Appl. Phys.* 58 (1985) 3766–74.

21 **K.L.I. Kobayashi, Y. Uchida, and H. Nakashima.** A model for DX centers: Bond reconstruction due to local random donor-host atom configurations in mixed semiconductor alloys. *Jpn. J. Appl. Phys.* 24 (1985) L928–31.

22 **T. Fukunaga, K.L.I. Kobayashi, and H. Nakashima.** Reduction of well width fluctuation in AlGaAs-GaAs single quantum well by growth interruption during molecular beam epitaxy. *Surf. Sci.*, Proceedings of the 2nd Int. Conf. Modulated Semicon. Struct., Kyoto, 1985.

23 **T. Narusawa and H. Nakashima.** Structure study of GaAs-dielectric films (CaF_2, Al_2O_3) interfaces by high energy ion scattering. *Proc. of the 168th Meeting of the Electrochem. Soc., Las Vegas* (1985) 332–40.

24 **T. Ohta, K.L.I. Kobayashi, and H. Nakashima.** Photoluminescence study of GaAs-AlGaAs multiquantum well grown by molecular-beam epitaxy. *Jpn. J. Appl. Phys.* 25 (1986) 59–63.

25 **Y. Uchida, K.L.I. Kobayashi, and H. Nakashima.** Electrical properties of DX center in $Al_xGa_{1-x}As$ and its bond reconstruction model. *Inst. Phys. Conf. Ser.* No. 79 (1986) 265–70.

26 **T. Fukunaga, K. Ishida, T. Kuroda, K. Matsui, T. Narusawa, T. Morita, E. Miyauchi, H. Hashimoto, and H. Nakashima.** Enhanced disordering of AlGaAs-GaAs multiquantum well by focused Si ion beam implantation. *Inst. Phys. Conf. Ser.* No. 79 (1986) 439–44.

27 **K. Ishida, T. Fukunaga, K. Matsui, J. Kobayashi, T. Morita, E. Miyauchi, H. Hashimoto, K. Ishida, and H. Nakashima.** Fabrication of disordered submicron pattern in GaAs-AlGaAs superlattice using focused Si ion beam. *Proc. of the 17th Symposium on Ion Implantation and Submicron Fabrication, Wako* (1986) 173–76.

28 **K. Matsui, S. Takatani, T. Fukunaga, T. Narusawa, Y. Bamba, and H. Nakashima.** Damage profile in GaAs, AlAs, AlGaAs, and GaAs/AlGaAs superlattices induced by Si^+–ion implantation. *Jpn. J. Appl. Phys.* 25 (1986) L391–93.

29 **K. Matsui, T. Takamori, T. Fukunaga, T. Narusawa, and H. Nakashima.** Ion–implanted damage in $Al_xGa_{1-x}As$ and superlattices studied by RBS. *Proc. of the 10th Sympo. on Ion Sources and Ion–Assisted Technology, ISIAT'86* (1986) 537–40.

30 **K. Ishida, K. Matsui, T. Fukunaga, T. Takamori, and H. Nakashima.** Fabrication of index–guided AlGaAs multiquantum well lasers with buried optical guide by Si–induced disordering. *Jpn. J. Appl. Phys.* 25 (1986) L690–92.

31 **K. Matsui, J. Kobayashi, T. Fukunaga, K. Ishida, and H. Nakashima.** Implantation energy dependence of compositional disordering in Si implanted GaAs/AlGaAs superlattices studied by secondary ion mass spectrometry. *Jpn. J. Appl. Phys.* 25 (1986) L651–53.

32 **K. Ishida, T. Takamori, K. Matsui, T. Fukunaga, T. Morita, E. Miyauchi, H. Hashimoto, and H. Nakashima.** Fabrication of index–guided AlGaAs MQW lasers by selective disordering using Be focused ion beam implantation. *Jpn. J. Appl. Phys.* 25 (1986) L783–85.

33 **Y. Uchida, T. Yokotsuka, T. Narusawa, and H. Nakashima.** Study of thermal stability of LaB_6 and GaAs interfaces by high energy ion scattering. *Jpn. J. Appl. Phys.* 25 (1986) L767–69.

34 **T. Fukunaga and H. Nakashima.** Photoluminescence from AlGaAs–GaAs single quantum wells with growth interrupted heterointerfaces grown on GaAs(100) and (311) substrates at various growth temperatures by molecular beam epitaxy. *Jpn. J. Appl. Phys.* 25 (1986) L856–58.

35 **H. Nakashima, J. Kobayashi, T. Fukunaga, K. Matsui, K. Ishida, M. Nakajima, Y. Bamba, and K. Ishida.** Correlation between Si diffusion and Si–induced disordering in AlGaAs/GaAs superlattices. *Superlattice and Microstructures* 2 (1986) 303–7.

36 **R. Bauer, D. Bimberg, J. Christen, D. Oertel, D. Marz, J.M. Miller, T. Fukunaga, and H. Nakashima.** Reduced dimensionality induced doublet splitting of heavy–hole excitons in GaAs quantum wells. *Proc. of the 18th International Conference on the Physics of Semiconductors.*

37 **K. Matsui, T. Takamori, T. Fukunaga, T. Narusawa, and H. Nakashima.** Ion-implantation induced damage in $Al_xGa_{1-x}As$ and superlattices studied by Rutherford backscattering. *Jpn. J. Appl. Phys.* 26, no. 3 (1987).

38 **S. Takatani, N. Matsuoka, J. Shigeta, T. Hashimoto, and H. Nakashima.** Thermal stability of WSi/GaAs interface. *J. Appl. Phys.* 61, no. 1 (1987).

39 **T. Narusawa, H. Ohyama, and H. Nakashima.** Structural study of GaAs-dielectric film (CaF_2, Al_2O_3) interfaces by high energy ion scattering. *J. Electrochem. Soc.* 134, no. 2 (1987).

40 **T. Fukunaga, T. Takamori, and H. Nakashima.** Photoluminescence from AlGaAs/GaAs single quantum wells grown on variously oriented GaAs superlattice by MBE. To be published in *J. Crystal Growth.*

41 **K. Ishida, K. Matsui, T. Fukunaga, T. Takamori, J. Kobayashi, K. Ishida, and H. Nakashima.** Si induced disordering and its application to fabrication of index-guided AlGaAs MQW lasers. To be published in *Inst. Phys. Conf. Ser.* (1987).

42 **Y. Uchida, S. Takatani, T. Yokotsuka, and H. Nakashima.** Electrical properties of thermally stable LaB_6/GaAs Schottky diodes. To be published in *Appl. Phys. Lett.*

43 **T. Yokotsuka, T. Narusawa, Y. Uchida, and H. Nakashima.** XPS study of Schottky barrier formation and thermal stability of LaB_6/GaAs(001)-*c*(4x4) interface. To be published in *Appl. Phys. Lett.*

Group 5 – Fabrication Technology

1 **Y. Mita, N. Tsukada, M. Hashimoto, S. Semura, and S. Sugata.** GaAs p-n junction formation by carbon ion implantation. Proceedings of the 14th Conference (1982 International) on Solid State Devices, Tokyo; *Jpn. J. Appl. Phys.* 22 (1983) Suppl. 22-1, 405-9.

2 **K. Asakawa.** Dry etching process for optoelectronic integrated circuit. *Post-Conference Meeting Tech. Digest 4th Int. Conf. Integrated Optics and Optical Fiber Communication, Kobe* (1983) p. 37.

3 **K. Asakawa and S. Sugata.** A new reactive ion beam etching system for clean-surface-oriented dry etching technology. *Proc. of the International Ion Engineering Congress ISIAT'83 & IPAT'83, Kyoto* (1983) 759-64.

4 **K. Asakawa and S. Sugata.** GaAs and GaAlAs equi-rate etching using a new reactive ion beam etching system. *Jpn. J. Appl. Phys.* 22 (1983) L653-55.

5 **S. Sugata, N. Tsukada, M. Nakajima, K. Kuramoto, and Y. Mita.** GaAs p-layer formation by Be ion implantation. *Jpn. J. Appl. Phys.* 22 (1983) L470-72.

6 **S. Sugata and K. Asakawa.** Investigation of GaAs surface morphology induced by Cl_2 gas reactive ion beam etching. *Jpn. J. Appl. Phys.* 22 (1983) L813-14.

7 **N. Tsukada, S. Sugata, and Y. Mita.** New experimental evidence of surface ripples on gallium arsenide in laser annealing. *Appl. Phys. Lett.* 42 (1983) 424–26.

8 **N. Tsukada, S. Sugata, H. Saitoh, and Y. Mita.** Surface ripples in laser-photochemical wet etching of gallium arsenide. *Appl. Phys. Lett.* 43 (1983) 189–91.

9 **Y. Mita, S. Sugata, and N. Tsukada.** Photoelectric probing of inhomogeneity in undoped, semi-insulating GaAs crystals. *Appl. Phys. Lett.* 43 (1983) 841–43.

10 **S. Sugata and K. Asakawa.** Study on GaAs and GaAlAs etchings by a new reactive ion beam etching system. *Proc. of the Symp. on Dry Process, Tokyo* (1983) 79–84.

11 **N. Tsukada, S. Sugata, H. Saitoh, K. Yamanaka, and Y. Mita.** Grating formation on gallium arsenide by one-step laser-photochemical etching. *Abstract of 2nd European Conference on Integrated Optics, Firenze* (1983) 105–7.

12 **S. Semura, H. Saitoh, and K. Asakawa.** Reactive ion etching of GaAs in CCl_4/H_2 and CCl_4/O_2. *J. Appl. Phys.* 55 (1984) 3131–35.

13 **K. Asakawa and S. Sugata.** Optical emission spectrum of Cl_2 ECR plasma in the GaAs reactive ion beam etching (RIBE) system. *Jpn. J. Appl. Phys.* 23 (1984) L156–58.

14 **S. Sugata and K. Asakawa.** GaAs radical etching with a Cl_2 plasma in a reactive ion beam etching system. *Jpn. J. Appl. Phys.* 23 (1984) L564–66.

15 **S. Semura and H. Saitoh.** Hydrogen mixing effects on reactive ion etching of GaAs in chlorine containing gases. *J. Vac. Sci. & Technol.* A2 (1984) 474–76.

16 **N. Tsukada, S. Semura, H. Saitoh, S. Sugata, K. Asakawa, and Y. Mita.** Laser-enhanced reactive ion etching of GaAs with CCl_4 and H_2 mixed gas. *J. Appl. Phys.* 55 (1984) 3417–20.

17 **K. Asakawa and S. Sugata.** GaAs and AlGaAs anisotropic fine pattern etching using a new reactive ion beam etching system. *J. Vac. Sci. & Technol.* B3 (1985) 402–5.

18 **S. Sugata and K. Asakawa.** GaAs and AlGaAs crystallographic etching with low pressure chlorine radical in ultra-high-vacuum RIBE system. *Proceedings of the 7th International Symposium on Plasma Chemistry, Eindhoven,* 3 (1985) 977–82.

19 **K. Asakawa and S. Sugata.** GaAs surface cleaning using radical beam gun with compact ECR plasma source. *Proc. of the Symp. on Dry Process, Tokyo* (1985) 138–43.

20 **S. Sugata and K. Asakawa.** Characterization of reactive ion beam etching-induced damage on GaAs using Schottky electrode technique. *Proc. of the Symp. on Dry Process, Tokyo* (1985) 144–48.

21 **K. Asakawa and S. Sugata**. Suppression of damage and contamination on reactive-ion-beam-etched GaAs surface using a novel UHV etching system with cleaning equipment. *Inst. Phys. Conf. Ser.* No. 79 (1986) 373–78.

22 **M. Uchida, S. Matsumoto, K. Asakawa, and H. Kawano**. Integrated AlGaAs two-beam LD-PD array fabricated by reactive ion beam etching. *Electron. Lett.* 22 (1986) 585–87.

23 **K. Asakawa and S. Sugata**. Damage and contamination-free GaAs and AlGaAs etching using a novel ultrahigh-vacuum reactive ion beam etching system with etched surface monitoring and cleaning method. *J. Vac. Sci. & Technol.* A4 (1986) 677–80.

24 **K. Asakawa**. GaAs and AlGaAs surface cleaning using an ECR radical beam gun. *Extended Abstracts of the 18th Conference on Solid State Devices and Materials, Tokyo* (1986) 129–32.

25 **N. Takado, K. Asakawa, H. Arimoto, S. Sugata, E. Miyauchi, and H. Hashimoto**. Chemically-enhanced GaAs maskless etching using a novel focused ion beam etching system with a chlorine molecular and radical beam. *Proc. of the 1986 U.S.A. Material Research Society Fall Meeting* (Symposium B).

26 **K. Asakawa, S. Sugata, and N. Takado**. Radical-surface interaction and its in-situ monitoring on GaAs and AlGaAs surfaces in an ultrahigh-vacuum etching and cleaning system. *J. Vacuum Science and Technology*.

27 **S. Sugata and K. Asakawa**. GaAs and AlGaAs crystallographic etching with low pressure chlorine radical in ultrahigh vacuum. To be published in *J. Vacuum Science and Technology B*.

28 **N. Takado, K. Asakawa, T. Yuasa, S. Sugata, E. Miyauchi, H. Hashimoto, and M. Ishii**. Chemically enhanced GaAs focused-ion-beam-etching of deep groove and laser-mirror facet under Cl_2 gas irradiation using a fine nozzle. Submitted to *Appl. Phys. Lett.*

Group 6 – Characterization

1 **T. Kikuta, K. Terashima, and K. Ishida**. Study of two different deep levels in undoped LEC SI-GaAs by photoluminescence spectroscopy. *Jpn. J. Appl. Phys.* 22 (1983) L409–11.

2 **T. Kikuta, K. Terashima, and K. Ishida**. Study of 0.8 eV deep level photoluminescence in undoped LEC semi-insulating GaAs. *Jpn. J. Appl. Phys.* 22 (1983) L541–43.

3 **K. Kuramoto, M. Nakajima, T. Kikuta, F. Orito, H. Emori, and K. Ishida**. Residual donor impurities in undoped LEC SI-GaAs crystals. *SIMS IV: Proceedings of the Fourth International Conference, Osaka, 1983* (Springer-Verlag, New York, 1984) 288–90.

4 **A. Yahata and M. Nakajima**. Effect of metals used for Schottky barrier contacts on DLTS signals for LEC n-GaAs crystals. *Jpn. J. Appl. Phys.* 23 (1984) L313–15.

5 **T. Kikuta, H. Emori, T. Fukuda, and K. Ishida.** Correlation between dominant deep PL bands and Fermi level in undoped LEC SI-GaAs. *Extended Abstracts of the 16th (1984 International) Conference on Solid State Devices and Materials, Kobe* (1984) 173–76.

6 **T. Sato, K. Terashima, S. Ozawa, M. Nakajima, T. Fukuda, and K. Ishida.** Effects of melt composition on electrical uniformity of Si implanted, undoped, semi-insulating GaAs. *Proc. of the IEEE Gallium Arsenide Integrated Circuit Symposium, Boston* (1984) 53–56.

7 **M. Nakajima, T. Katsumata, K. Terashima, and K. Ishida.** Striations in undoped semi-insulating LEC GaAs. *Jpn. J. Appl. Phys.* 24 (1985) L65–68.

8 **K. Ishida, A. Yahata, and T. Kikuta.** Distinction between midgap levels in LEC n–GaAs determined by DLTS and optical absorption at 1.1 micrometers. *Jpn. J. Appl. Phys.* 24 (1985) L250–52.

9 **N. Tsukada, T. Kikuta, and K. Ishida.** Intracenter transition in EL2 observed in photocurrent spectrum. *Jpn. J. Appl. Phys.* 24 (1985) L302–4.

10 **T. Sato, K. Terashima, H. Emori, S. Ozawa, M. Nakajima, T. Fukuda, and K. Ishida.** Effect of melt stoichiometry on electrical activation uniformity of Si–implanted layers in undoped semi-insulating GaAs. *Jpn. J. Appl. Phys.* 24 (1985) L488–90.

11 **T. Kikuta, T. Katsumata, T. Obokata, and K. Ishida.** Microscopic distribution of deep and shallow levels around dislocations in undoped SI–GaAs. *Inst. Phys. Conf. Ser.* No. 74 (1985) 47–52.

12 **K. Ishida, T. Ohta, S. Semura, and H. Nakashima.** Cross sectional transmission electron microscopy of Zn diffusion induced disordering of GaAlAs–GaAs multiquantum–well structures. *Jpn. J. Appl. Phys.* 24 (1985) L620–22.

13 **N. Tsukada, T. Kikuta, and K. Ishida.** Photo–electron paramagnetic resonance study of As_{Ga} antisite defect in as–grown GaAs crystals of different stoichiometry. *Jpn. J. Appl. Phys.* 24 (1985) L689–92.

14 **A. Yahata, T. Sato, T. Kikuta, and K. Ishida.** Detailed analysis of DLTS signals of EL2 in LEC n–GaAs crystals. *Materials Research Society Symposia Proceeding* 46 (1985) 179–84.

15 **N. Tsukada, T. Kikuta, and K. Ishida.** Identification of As_{Ga} antisite defect by stoichiometry dependent EPR photoresponse. *Inst. Phys. Conf. Ser.* No. 79 (1986) 205–10.

16 **A. Yahata, T. Kikuta, and K. Ishida.** Three midgap levels in LEC n–GaAs determined by DLTS using Au and Al Schottky barrier diodes. *Jpn. J. Appl. Phys.* 25 (1986) L133–36.

17 **N. Tsukada, T. Kikuta, and K. Ishida.** Reply to "comment on intracenter transition in EL2 observed in photocurrent spectrum." *Jpn. J. Appl. Phys.* 25 (1986) L196–97.

18 **K. Ishida, M. Akiyama, and S. Nishi.** Characterization of lattice defect structures at GaAs/Si interface by transmission electron microscopy. *Jpn. J. Appl. Phys.* 25 (1986) 288–90.

19 **J. Kobayashi, M. Nakajima, Y. Bamba, T. Fukunaga, K. Matsui, K. Ishida, H. Nakashima, and K. Ishida.** SIMS study of compositional disordering in Si ion implanted AlGaAs–GaAs superlattice. *Jpn. J. Appl. Phys.* 25 (1986) L385–87.

20 **N. Tsukada, T. Kikuta, and K. Ishida.** Zero–phonon line associated with the midgap level EL2 in GaAs: Correlation with the As_{Ga} antisite defect. *Phys. Rev.* B33 (1986) 8859–62.

21 **T. Kikuta, H. Emori, T. Fukuda, and K. Ishida.** Carbon in undoped LEC semi–insulating GaAs; Origin and melt composition dependence. *J. Cryst. Growth* 76 (1986) 517–20.

22 **J. Kobayashi, M. Nakajima, T. Fukunaga, T. Takamori, K. Ishida, H. Nakashima, and K. Ishida.** SIMS study of Si–Be co–doping effects for suppression of compositional disordering in AlGaAs–GaAs superlattices. *Jpn. J. Appl. Phys.* 25 (1986) L736–38.

23 **N. Tsukada, T. Kikuta, and K. Ishida.** Identification of a defect associated with the zero–phonon line in EL2 absorption as the neutral charge state of As_{Ga}. *Semi–Insulating III–V Materials, Hakone* (1986) 367–72.

24 **M. Tajima, A. Yahata, T. Kikuta, and K. Ishida.** Correlation of EL2–related signals in GaAs obtained by photoluminescence, absorption and deep level transient spectroscopy. *Semi–Insulating III–V Materials, Hakone* (1986) 305–10.

25 **N. Nakajima, T. Sato, T. Inada, and K. Ishida.** Evaluation of stoichiometry in undoped semi–insulating GaAs by absolute lattice parameter measurements. *Semi–Insulating III–V Materials, Hakone* (1986) 181–86.

26 **A. Yahata, H. Okushi, and K. Ishida.** Effect of metal/semiconductor reactions on transient capacitance measurements for EL2 in LEC n–GaAs crystals. *Semi–Insulating III–V Materials, Hakone* (1986) 415–20.

27 **M. Tajima.** Deep level photoluminescence in GaAs. *Defects and Properties of Semiconductors: Defect Engineering,* edited by J. Chikawa, K. Sumino, and K. Wada, KTK Scientific Publisher, Tokyo (1987) 37–69.

28 **M. Nakajima, T. Sato, T. Inada, T. Fukuda, and K. Ishida.** Study of nonstoichiometry in undoped semi–insulating GaAs using precise lattice parameter measurements. *Appl. Phys. Lett.* 49 (1986) 1251–53.

29 **K. Ishida and H. Kawano.** Different etch pit shapes revealed by molten KOH etching on the (001)GaAs surface and their dependence on the Burgers vectors. *Phys. Stat. Sol.* (a) 98, 175 (1986).

30 **T. Sato, M. Nakajima, T. Fukuda, and K. Ishida.** Stoichiometry dependence of electrical activation efficiency in Si implanted layers of undoped semi–insulating GaAs. *Appl. Phys. Lett.* 49 (1986) 1599–1601.

31 **M. Tajima.** Zero–phonon line of deep–level luminescence in GaAs. *Proc. of the International Conference on Defect in Semiconductor.*

32 **M. Tajima, H. Tanino (ETL), and K. Ishida.** Radiative recombination mechanism of deep levels in GaAs. *Proc. of the International Conference on Defect in Semiconductor.*

33 **J.D. Flood*, G. Bahir*, J.L. Merz*, J. Kobayashi, T. Fukunaga, K. Ishida, and H. Nakashima** (*UCSB). Effect of Si implantation and rapid thermal annealing on GaAs/AlGaAs superlattice disordering. *Proc. of U.S.A. Material Research Society 1986 Fall Meeting.*

34 **T. Kikuta and K. Ishida.** Role of boron in SI LEC GaAs. *Proc. of the 1986 International Symposium on GaAs and Related Compounds.*

35 **J. Kobayashi, T. Fukunaga, K. Ishida, H. Nakashima, J.D. Flood*, G. Bahir*, and J.L. Merz*** (*UCSB). The effect of rapid thermal annealing for the compositional disordering of Si implanted AlGaAs/GaAs superlattice. To be published in *Appl. Phys. Lett.*

36 **K. Ishida, M. Akiyama*, and S. Nishi*** (*Oki Electric). Misfit and threading dislocations in GaAs/Si. To be published in *Jpn. J. Appl. Phys. Lett.*

37 **I. Kuramoto, H. Sato, and K. Ishida.** Coulometric determination of arsenic in undoped LEC SI–GaAs. To be published in *J. Electrochemical Society.*

38 **J. Kobayashi, M. Nakajima, and K. Ishida.** The sources for contaminants in the trace analysis of carbon in GaAs by SIMS. Submitted to *J. Vacuum Science and Technology A.*

Group S – Review Papers

1 **T. Iizuka, T. Fukuda, H. Hashimoto, and K. Asakawa.** Fabrication technology for optoelectronic integrated circuits. *Extended Abstracts of the 5th International Conference on Integrated Optics and Optical Fibre Communication, Venezia* (1985) 65–72.

2 **I. Hayashi.** Future direction of optoelectronics: Basic concepts of optoelectronic integration. *Optoelectronics–Devices and Technologies,* Vol 1, No. 1 (1986) 1–10.

3 **I. Hayashi.** Research aiming for future optoelectronic integration. *IEE Proceedings,* Vol 133, Pt. J, No. 3 (1986) 237–44.

INTERNATIONAL MEETINGS IN THE FAR EAST

1987-1994

Compiled by Yuko Ushino

Yuko Ushino is a technical information specialist for ONR Far East. She received a B.S. degree from Brigham Young University at Provo, Utah.

The Australian Academy of Science, the Japan Convention Bureau, and the Science Council of Japan are the primary sources for this list. Readers are asked to notify us of any upcoming international meetings and exhibitions in the Far East which have not yet been included in this report.

1987

Date	Title, Attendance	Site	For information, contact
June 2-5	Transducers '87 20-F200-J600*	Tokyo, Japan	Secretariat: Transducer'87 c/o Sansei International Inc., Fukide No. 2 Building 4-1-21 Toranomon, Minato-ku, Tokyo 105
June 8-12	1987 International Congress on Membranes and Membrane Processes (ICOM'87) 30-F200-J400	Tokyo, Japan	Institute of Industrial Science, University of Tokyo 7-22-1 Roppongi, Minato-ku, Tokyo 106
June 22-25	The 1st Congress of Asian Federation of Societies for Ultrasound in Medicine and Biology 20-F50-J300	Tokyo, Japan	Japan Society of Ultrasonics Medicine c/o International Conference Organizers, Inc. 2-4-6 Minamiaoyama, Minato-ku, Tokyo 107
June 29-July 3	Asian Chemical Congress	Seoul, Korea	Korean Chemical Association 35 5-ga Anam-dong, Songbuk-gun, Seoul 132
July 6-10	The 6th International Conference on the Physics of Non-Crystalline Solids F70-J130	Kyoto, Japan	Professor F. Sakka, The Institute for Chemical Research, Kyoto University Gokanosho, Uji-City, Kyoto 611
July 13-18	The 34th International Field Emission Symposium F40-J80	Osaka, Japan	Dr. Shogo Nakamura, The Institute of Scientific and Industrial Research, Osaka University 8-1 Mihongaoka, Ibaraki-shi, Osaka 567

*Note: Data format was taken from the Japan International Congress Calendar published by the Japan Convention Bureau.

No. of participating countries
F: No. of overseas participants
J: No. of Japanese participants

Date	Title, Attendance	Site	For information, contact
July 19-24	The International Conference on Heteroatom Chemistry-IUPAC 300-F100-J400	Kobe, Japan	Institute for Chemical Research, Kyoto University Gokasho, Uji, Kyoto 611
July 20-25	The Second IFSA (Italy, France, Spain, America) Congress (2nd IFSA Congress)	Tokyo, Japan	Secretariat: The Second IFSA Congress c/o The Society of Instrument and Control Engineers, 1-35-28-303 Hongo, Bunkyo-ku, Tokyo 113
July 26-31	XXV International Conference on Coordination Chemistry	Nanjing, People's Republic of China	Professor Xiao-Zeng You, Secretary, XXXV ICCC, Coordination Chemistry Institute, Nanjing University Nanjing, Jiangsu Province
Undecided	The International Conference on Computers in Chemical Research and Education (the ICCCRE)	Shanghai, People's Republic of China	Dr. Yongzheng Hui, Shanghai Institute of Organic Chemistry, Academia Sinica 345 Lingling Lu, Shanghai 200032
August 3-6	The International Conference on Mechanical Dynamics	Shenyang, People's Republic of China	Professor Wen Bangchun, Chairman, ICMD Organizing Committee Box 319, Northeast University of Technology Shenyang, Liaoning
August 5-7	Pacific Conference on Earthquake Engineering	Wairakei, New Zealand	Secretariat: NZNSEE Box 243, Wellington
August 8-10	Neutron Scattering Symposium 1987	Sydney, Australia	Professor T. M. Sabine, School of Physics and Materials, NSW Institute of Technology P.O. Box 123, Broadway, NSW 2007
August 12-20	The 14th General Assembly and International Congress of Crystallography 46-F1,400-J100	Perth, Australia	Dr. E.N. Maslen, Crystallography Centre, University of Western Australia Nedlands WA 6009
August 17-21	1987 Luminescence International Conference	Beijing, People's Republic of China	Professor Xu Xurong, Chinese Society of Luminescence Xinmin Street 13 Chang-chun, People's Republic of China
August 19-26	The 18th International Conference on Low Temperature Physics 38-F600-J750	Kyoto, Japan	Professor Shinji Ogawa, The Institute for Solid State Physics, Tokyo University 7-22-1 Roppongi, Minato-ku, Tokyo 106

Date	Title, Attendance	Site	For information, contact
August 20-30	XVI Pacific Science Congress	Seoul, Korea	Professor Choon Ho Park, Secretary General, Organizational Committee, XVI PSC K.P.O. Box 1008, Seoul 110
August 23-27	The 4th International Conference on Solid Films and Surfaces	Hamamatsu, Japan	Dr. Goro Shimaoka, Research Institute of Electronics, Shizuoka University 3-5-1 Johoku, Hamamatsu-city, Shizuoka 432
August 24-27	The 7th International Conference On Quarks-Leptons Physics in Collision 15-F130-J80	Tsukuba, Japan	Organizing Committee: The 7th International Conference on Physics in Collision c/o National Laboratory for High Energy Physics, 1-1 Uehara, Ohomachi, Tsukuba-gun, Ibaraki 305
August 25-28	IUTAM Symposium on Non-linear Water Waves	Tokyo, Japan	Professor H. Maruo, Department of Naval Architecture, Yokohama National University Tokiwa-dai, Hodogaya-ku, Yokohama 240
August 26-29	Pacific Rim Congress 87 International Congress on the Geology Structure, Mineralisation and Economics of the Pacific Rim	Gold Coast, Australia	Mr. E. Brennan, Congress Convenor, The Australasian Institute of Mining Metallurgy, Clunies Ross House Royal Parade, Parkville, Victoria 3052
August 27-29	International Summer School on Plasma Chemistry	Atami, Japan	ISSPC c/o Electronic Mechanical Engineering, Faculty of Engineering, Nagoya University, Furo-cho, Jikusaku-ku, Nagoya-city 464
August 27-30	The 6th International Conference on Biomagnetism 20-F300-J500	Tokyo, Japan	Secretariat: The 6th International Conference on Biomagnetism c/o INTER Group, Akasaka Yamakatsu Building, 8-5-32, Akasaka, Minato-ku, Tokyo 107
August 31-September 1	Yamada Conference XVIII on Superconductivity in Highly Correlated Fermion Systems-YCS '87 F120-J80	Sendai, Japan	Secretariat: YCS '87 c/o Research Institute for Iron, Steel and Other Metals, Tohoku University, 2-1-1 Katahira, Sendai 980

Date	Title, Attendance	Site	For information, contact
August 31–September 4	The 8th International Symposium on Plasma Chemistry	Tokyo, Japan	Professor Kazuo Akashi, Metallurgy, Faculty of Engineering, University of Tokyo 7-3-1 Hongo, Bunkyo-ku, Tokyo 113
August 31–September 4	IUTAM Fundamental Aspects of Vortex Motion 10-F40-J60	Tokyo, Japan	Secretariat: Department of Physics, University of Tokyo 7-3-1 Hongo, Bunkyo-ku, Tokyo 113
August (tentative)	The 10th International Congress of Pharmacology	Sydney, Australia	Professor J. Shaw, Secretary, Interium Organising Committee, Department of Pharmacology, University of Sydney NSW 2006
August (tentative)	International Congress for Pharmacology, Satellite on Cardio-Active Drugs	Hayman Island, Australia	Australian Convention and Travel Services GPO Box 1929, Canberra, ACT 2601
September 1-5	The 4th JECSS (Japan and East China Seas Study) Workshop	Tsukuba, Japan	Kei Muneyama, JAMSTEC, 2-15 Natsushima-cho, Yokosuka 237
September 2-4	The 12th International Symposium of Hosei University "Application of Ion Beams in Material Science"	Tokyo, Japan	Research Center for Ion Beam Technology 3-7-2 Kajino-cho, Koganei-city, Tokyo 184
September 2-4	Structural Engineering Conference	Melbourne, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
September 6-11	The 6th Pacific Basin Conference	Beijing, People's Republic of China	Dr. Chih Wang, 3110 Chintimini Drive, Corvallis, Oregon 97330, U.S.A.
September 16-18	International Symposium on Optical Memory	Tokyo, Japan	Optoelectronic Industry and Technology Development Association 5th Floor, No. 20 Mori Building, 2-7-4 Nishi-Shimbashi, Minato-ku, Tokyo 105
September 20-24	The 7th Asian and Oceanian Congress of Neurology 25-F610-J140	Bali, Indonesia	Professor Soemargo Sastrodiwirjo, The 7th Asian and Oceanian Congress of Neurology, RSCM/FKUI Salemba 6, Jakarta Pusat 10430

Date	Title, Attendance	Site	For information, contact
September (tentative)	International Computer Graphics Symposium 4-F60-J300	Sapporo, Japan	Incorporated Foundation Sapporo Electronics Center 31 Shimonopporo, Atsubetsucho, Shi[illegible]shi-ku, Sapporo 004
September (tentative)	Submarine Technology Conference	Canberra, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
October 5-8	The 5th International Workshop on Database Machines	Karuizawa, Japan	Professor M. Kitsuregawa, I.W.D.M. Secretariat c/o Inter Group Corporation, Akasaka Yamakatsu Building, 8-5-32 Akasaka, Minato-ku, Tokyo 107
October 5-9	IEEE Computer Society's 11th International Computer Software and Applications Conference 20-F400-J900	Tokyo, Japan	c/o Information Processing Society of Japan 2-40-14 Hongo, Bunkyo-ku, Tokyo 113
October 5-9	The 4th Asian-Pacific Regional Meeting (IAU)	Beijing, People's Republic of China	Dr. Q.B. Li, Beijing Astronomical Observatory, Academia Sinica Beijing
October 6-9	IMACS/IFAC International Symposium on Modeling and Simulation of Distributed Parameter Systems 20-F50-J110	Hiroshima, Japan	Professor Tanehiro Futagami, Civil Engineering, Hiroshima Institute of Technology 725 Miyake, Itsukaichi-cho, Saeki-ku, Hiroshima 731-51
October 12-16	The 12th International Conference on Atomic Collisions in Solids 20-F80-J160	Okayama, Japan	Professor Fuminori Fujimoto, Physics Section, College of General Education, University of Tokyo 3-8-1 Komaba, Meguro-ku, Tokyo 153
October 12-16	Chapman Conference on Plasma Waves and Instabilities in Magnetospheres and at Comets F100-J50	Miyagi, Japan	Faculty of Science, Tohoku University Aoba, Aramaki, Sendai 980
October 14-17	Tokyo Seminar on Macromolecule-Metal 10-F50-J150	Tokyo, Japan	Organizing Committee, Tokyo Seminar on Macromolecule-Metal Complexes c/o Ibaraki University, Bunkyo, Mito 310

1987

Date	Title, Attendance	Site	For information, contact
October 15-16	Microoptics Conference '87	Tokyo, Japan	Professor Kenichi Iga, Program Cochair MOC '87, Tokyo Institute of Technology 4259 Nagatsuta, Midori-ku, Yokohama 227
October 18-24	International Towing Tank Conference (ITTC) 30-F100-J100	Kobe, Japan	Society of Naval Architects of Japan (SNAJ) Sempaku-Shinko Building, 8th Floor, 1-15-16 Toranomon, Minato-ku, Tokyo 105
October 20-23	International Conference on Quality Control--1987 Tokyo 45-F350-J400	Tokyo, Japan	Union of Japanese Scientists and Engineers 5-10-11 Sendagaya, Shibuya-ku, Tokyo 151
October 24-25	International Conference on Lasers	People's Republic of China	Professor Wang Zhi-Jiang, Shanghai Institute of Optics and Fine Mechanics P.O. Box 8211, Shanghai
October 26-29	The 2nd International Symposium on Transport Phenomena in Turbulent Flows 20-F100-J150	Tokyo, Japan	Department of Mechanical Engineering, University of Tokyo 7-3-1 Hongo, Bunkyo-ku, Tokyo 113
October 26-30	1987 Tokyo International Gas Turbine Congress	Tokyo, Japan	c/o Nissei Kogyo K.K. 2-5-10 Nishi-Shinbashi, Minato-ku, Tokyo 105
November 2-4	The 6th Symposium of the Federation of Asian and Oceanian Biochemists 20-F280-J20	Karachi, Pakistan	Dr. A. Rahman, Department of Biochemistry, Jinnah Post-Graduate Medical Centre, Karachi
November 3-6	The 3rd International Photovoltaic Science and Engineering Conference 23-F150-J300	Tokyo, Japan	Japan Society of Applied Physics c/o Japan Convention Service, Inc. 2-2-1 Uchisaiwai-cho, Chiyoda-ku, Tokyo 100
November 4-6	'87 International Symposium on Science and Technology of Sintering	Tokyo, Japan	Professor Shigeyuki Somiya, Sintering '87, Tokyo c/o Nikkan Kogyo Shimbun, Ltd., Planning Bureau, 8-10 Kudan Kita 1-chome, Chiyoda-ku, Tokyo 102
November 7-11	The 10th International Congress on Metallic Corrosion	Madras, India	Lois Baigée, National Research Council of Canada Ottawa ON K1A OR6

1987

Date	Title, Attendance	Site	For information, contact
November 9-12	The 19th Yamada Conference on Ordering and Organization in Ionic Solutions 10-F40-J100	Kyoto, Japan	Department of Polymer Chemistry, Kyoto University Yoshida-hommachi, Sakyo-ku, Kyoto 600
November 9-13	The 2nd International Conference on Refractories 6-F170-J270	Tokyo, Japan	Secretariat: The 2nd International Conference on Refractories c/o International Congress Service, Inc., Kasho Building, 2-14-9 Nihombashi, Chuo-ku, Tokyo 103
November 15-18	1987 Global Telecommunications Conference (GLOBECOM'87) 30-F500-J700	Tokyo, Japan	Secretariat: GLOBECOM'87 c/o KDD Research and Development Laboratories, 2-1-23 Nakameguro, Meguro-ku, Tokyo 153
November 25-27	The 18th Japan Conference on Radiation and Radioisotopes 30-F60-J600	Tokyo, Japan	Japan Atomic Industrial Forum, Inc. Toshin Building, 1-1-13 Shimbashi, Minato-ku, Tokyo 105
December 7-11	The 7th International Conference on Thin Films (ICTF-7)	New Delhi, India	Dr. Lalit Malhotra, Secretary, ICTF-7, Department of Physics, Indian Institute of Technology New Delhi, 110016

1988

Date	Title, Attendance	Site	For information, contact
January 28-31	Royal Australian Chemical Institute, Division of Inorganic Chemistry, National Meeting (COMO 13)	Melbourne, Australia	Dr. P. Tregloan, Department of Inorganic Chemistry, University of Melbourne Parkville, Victoria 3052
February 2-5	The International Association of the Institute of Navigation (IAIN) Congress	Sydney, Australia	The Australian Institute of Navigation Box 2250, G.P.O., Sydney, New South Wales, Australia 2001
February 2-5	A Congress of the International Association of Institutes of Navigation	Sydney, Australia	Professor Günther Zade, World Maritime University P.O. Box 500, S-20124 Malmö, Sweden
February 22-26	Engineering Conference	Sydney, Australia	The Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600

1988

Date	Title, Attendance	Site	For information, contact
February (tentative)	The 10th Australian Electron Microscopy Conference	(Undecided)	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601
March 14-16	International Symposium on Non-Equilibrium Solid Phase of Metals and Alloys F 00-J200	Kyoto, Japan	Department of Metal Science and Technology, Faculty of Engineering, Kyoto University Yoshida-hommachi, Sakyo-ku, Kyoto 600
April 4-12	The 4th International Conference on Aluminium Association (JLWA) 32-F100-J150	Tokyo, Japan	Japan Light Metal Welding and Construction Weldment Yura Building, 3-37-23, Kanda-Sakumacho, Chiyoda-ku, Tokyo 101
April 19-23	International Conference on Nuclear Power Plant Water Chemistry-Operation Experience and Sophisticated Management Technology	(to be decided)	Japan Atomic Industrial Forum, Inc. Toshin Building, 1-1-23 Shimbashi, Minato-ku, Tokyo 105
April 26-May 3	The 3rd World Biomaterials Conference 15-F500-J500	Kyoto, Japan	Japan Society for Biomaterials c/o Institute for Medical and Dental Engineering, Tokyo Medical and Dental University, 2-3-10 Kanda-Surugadai, Chiyoda-ku, Tokyo 101
May 16-20	The 4th International Conference on Metalorganic Vapor Phase Epitaxy	Hakone, Japan	Professor T. Katoda, Secretary, ICMOVPE IV c/o International Congress Service, Inc., Kasho Building 2F, 2-14-9 Nihombashi Chuo-ku, Tokyo 103
May 25-27	The 5th International Microelectronics Conference (IMC 1988)	Tokyo, Japan	Dr. H. Hirabayashi, ISHM Japan Chapter 6-20-4 Hanakoganei, Kodaira-city, Tokyo 187
June 5-10	The 6th International Conference on Surface and Colloid Science	Hakone, Japan	Division of Colloid and Surface Chemistry, The Chemical Society of Japan 1-5 Kanda-Surugadai, Chiyoda-ku, Tokyo 101
June 6-10	International Conference on Physical Metallurgy of Thermomechanical Processing of Steels and Other Metals 20-F100-J100	Tokyo, Japan	Nippon Tekko Kyokai 3rd Floor, Keidanren Kaikan, 1-9-4 Otemachi, Chiyoda-ku, Tokyo 100

1988

Date	Title, Attendance	Site	For information, contact
June 7-10	International Conference on Precision Electro-magnetic Measurements (CPEM'88)	Tsukuba, Japan	The Society of Instrument and Control Engineers 1-35-28-303 Hongo, Bunkyo-ku, Tokyo 113
June 7-10	The 7th International Conference on Ion Implantation Technology (IIT'88)	Kyoto, Japan	Professor Isao Yamada, Ion Beam Engineering Experimental Laboratory, Kyoto University Sakyo, Kyoto 606
June 12-17	The International Conference on Ion Beam Modification of Materials (IBMM'88)	Tokyo, Japan	Professor Susumu Nanba, Faculty of Engineering Science, Osaka University 1-1 Machikaneyama-cho, Toyonaka-city, Osaka 560
July 1-12	The 16th International Congress of Photogrammetry and Remote Sensing 48-F2,000-J2,600	Kyoto, Japan	Japan Society of Photogrammetry 601 Daiichi Honan Building, 2-8-17 Minami-Ikebukuro, Toshima-ku, Tokyo 171
July 12-15	The 6th International Conference on Ultrafast Phenomena 20-F200-J200	Shiga, Japan	The 6th International Conference on Ultrafast Phenomena Organization Committee c/o OPTO Marketing Service Ltd., Maenocho Heights 5-206, 6-10 Maenocho, Itabashi-ku, Tokyo 174
July 17-23	International Congress of Endocrinology 48-F2,000-J2,600	Kyoto, Japan	Japan Endocrine Society c/o Seirenkaikan, Kyoto Furitsu Medical University, Nishizume Konjinbashi, Kamigyo-ku, Kyoto 602
July 18-22	International Symposium on Scale Modeling	Tokyo, Japan	Secretariat: c/o The Japan Society of Mechanical Engineers, Sanshin Hokusei Building, 2-4-9 Yoyogi, Shibuya-ku, Tokyo 151
July 18-22	1988 XVI International Conference on Quantum Electronics 30-F300-J700	Tokyo, Japan	Optoelectronic Industry and Technology Development Association No. 20 Mori Building, 2-74 Nishi-shimbashi, Minato-ku, Tokyo 105
July 25-30	International Conference on Clustering Aspects in Nuclear and Subnuclear Systems 31-F150-J150	Kyoto, Japan	Dr. K. Tanaka, Faculty of Science, Hokkaido University 5-chome, Kita 10-jo, Kita-ku, Sapporo 060

1988

Date	Title, Attendance	Site	For information, contact
August 1-5	The 10th Congress of the International Ergonomics Association	Sydney, Australia	Ergonomics Society of Australia and New Zealand, Science Centre 35-43 Clarence Street, Sydney, NSW 2000
August 1-6	The IUPAC 32nd International Symposium on Macromolecules 50-F600-J1,200	Kyoto, Japan	The Society of Polymer Science, Japan 5-12-8 Ginza, Chuo-ku, Tokyo 104
August 14-19	The 10th International Congress on Rheology	Sydney, Australia	R. I. Tanner, Department of Mechanical Engineering, University of Sydney NSW 2006
August 15-17	International Federation of Automatic Control Symposium	Melbourne, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
August 15-17	Electrical IFAC Conference	Melbourne, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
August 15-19	The 3rd International Phycological Congress	Melbourne, Australia	Dr. M. N. Clayton, Botany Department, Monash University Clayton, Victoria 3168
August 16-19	The 7th International IUPAC Symposium on Mycotoxins and Phycotoxins 38-F100-J200	Tokyo, Japan	Japan Association of Mycotoxicology, Science University of Tokyo c/o Science University of Tokyo, 12 Fungagawara-machi, Ichigaya, Shinjuku-ku, Tokyo 160
August 21-26	International Geographical Congress	Sydney, Australia	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601
August 22-26	The 5th Australia-New Zealand Conference on Geomechanics	Sydney, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600
August 30-September 2	The 5th International Conference on Molecular Beam Epitaxy 15-F150-J400	Hokkaido, Japan	Japan Society of Applied Physics c/o Department of Physical Electronics, Tokyo Institute of Technology 2-12-1, Oh-okayama, Meguro-ku, Tokyo 152
September 5-8	The 1st International Conference on Computational Methods in Flow Analysis F250-J300	Okayama, Japan	Okayama University of Science 1-1 Ridaicho, Okayama 700

1988

Date	Title, Attendance	Site	For information, contact
October 17-20	The 9th International Conference on Pattern Recognition	Beijing, People's Republic of China	9 ICPR Secretariat: Chinese Association of Automation P.O. Box 2728, Beijing
November 2-5	International High-Performance Vehicle Conference	Shanghai, People's Republic of China	Ship Design Committee CSNAME P.O. Box 3053, Shanghai
November 19-26	The 13th International Diabetes Federation Congress 20-F80-J120	Sydney, Australia	Professor J. R. Turtle, Professor of Medicine Department of Endocrinology, University of Sydney NSW 2006

1989

Date	Title, Attendance	Site	For information, contact
July 2-7	XXVII International Conference on Coordination Chemistry	Brisbane, Australia	Professor Clifford J. Hawkins, Department of Chemistry, University of Queensland Saint Lucia, Brisbane, Queensland 4067
August 13-18	Solar Energy Congress Tokyo 1989 40-F600-J400	Tokyo, Japan	Japanese Section of International Solar Energy Society 322 San Patio, 3-1-5 Takada-no-baba, Shinjuku-ku, Tokyo 160
October (tentative)	Specialty Electric Conference	Sydney, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
1989 (tentative)	International Conference Evaluation of Materials Performance in Severe Environments-Evaluation and Development of Materials in Civil and Marine Uses 20-F80-J120	Japan (undecided)	International Conference Secretariat, Conference and Editorial Department, Iron and Steel Institute of Japan 1-9-4 Otemachi, Chiyoda-ku, Tokyo 100
1989 (tentative)	International Conference on Zinc and Zinc Alloy Coated Sheet Steels 20-F50-J150	Japan (undecided)	International Conference Secretariat, Conference and Editorial Department, Iron and Steel Institute of Japan 1-9-4 Otemachi, Chiyoda-ku, Tokyo 100

1990

Date	Title, Attendance	Site	For information, contact
May 19-26	The 27th International Navigation Congress 60-F500-J500	Japan (undecided)	Japan Organizing Committee for 27th International Navigation Congress 2-8-24 Chikko, Minato-ku, Osaka 552
July (tentative)	The 10th International Congress of Nephrology 10-F1,000-J4,000	Osaka, Japan	Japanese Society of Nephrology c/o 2nd Department of Internal Medicine, School of Medicine, Tokyo 173
August 21-29	International Congress of Mathematicians	Kyoto, Japan	Research for Mathematical Sciences, Kyoto University Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto 606
September (tentative)	The 15th International Congress on Microbiology 57-F2,500-J2,500	Osaka, Japan	Preliminary Committee of International Congress of Microbiology c/o JTB Creative Inc., Daiko Building, 3-2-14 Umeda, Kita-ku, Osaka 530
1990 (tentative)	The 6th International Conference on the Science and Technology of Iron and Steel 50-F300-J500	Japan (undecided)	International Conference Secretariat and Editorial Department, Iron and Steel Institute of Japan 3F, Keidanren Kaikan, 1-9-4 Otemachi, Chiyoda-ku, Tokyo 100
1990 (tentative)	Chemeca 1990 Applied Thermodynamics	New Zealand	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600

1991

Date	Title, Attendance	Site	For information, contact
August (tentative)	The 16th International Conference on Medical and Biological Engineering 45-F600-J900	Kyoto, Japan	ME Division, Kawasaki Medical School 577 Matsushima, Kurashiki City, Okayama 701-01
August (tentative)	International Congress on Medical Physics 45-F600-J900	Kyoto, Japan	National Institute of Radiological Science 4-9-1 Anagawa, Chiba 260

1992

1993

Date	Title, Attendance	Site	For information, contact
1993 (tentative)	International Federation of Automatic Control Congress	Sydney, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600

1994

Date	Title, Attendance	Site	For information, contact
Tentative	XXX International Conference on Coordination Chemistry	Kyoto, Japan	Professor Hitoshi Ohtaki, Department of Electronic Chemistry, Tokyo Institute of Technology at Nagatsuta 4259 Nagatsuta-cho, Midori-ku, Yokohama 227

U.S. GOVERNMENT PRINTING OFFICE : 1987 O - 186-826

CHANGE REQUEST

This form is provided for your convenience to indicate necessary changes or corrections in mailing the ***Scientific Bulletin*** to you.

Please continue sending me the Scientific Bulletin ________________

Please make the address change as indicated ________________

Please discontinue sending me the ***Scientific Bulletin*** ________________

Old Address ________________________________

New Address ________________________________

NOTICE

The Office of Naval Research/Air Force Office of Scientific Research/Army Research Office, Liaison Office, Far East is located on the second floor of Bldg #1, Akasaka Press Center and bears the following mail identification:

Mailing address:	Office of Naval Reseach/Air Force Office of Scientific Research/Army Research Office Liaison Office, Far East APO San Francisco 96503-0007
Local address:	ONR/AFOSR/ARO Far East Akasaka Press Center 7-23-17, Roppongi Minato-ku, Tokyo 106
Telephone numbers:	Civilian 03-401-8924 Autovon 229-3236 Telefax 03-403-9760

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY CARD

FIRST CLASS PERMIT NO. 12503 WASH., D.C.

POSTAGE WILL BE PAID BY DEPARTMENT OF THE NAVY

OFFICE OF NAVAL RESEARCH
LIAISON OFFICE, FAR EAST
APO SAN FRANCISCO 96503-0007

1993

Date	Title, Attendance	Site	For information, contact
1993 (tentative)	International Federation of Automatic Control Congress	Sydney, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600

1994

Date	Title, Attendance	Site	For information, contact
Tentative	XXX International Conference on Coordination Chemistry	Kyoto, Japan	Professor Hitoshi Ohtaki, Department of Electronic Chemistry, Tokyo Institute of Technology at Nagatsuta 4259 Nagatsuta-cho, Midori-ku, Yokohama 227

☆ U.S. GOVERNMENT PRINTING OFFICE : 1987 O - 186-826

END
11-87
DTIC